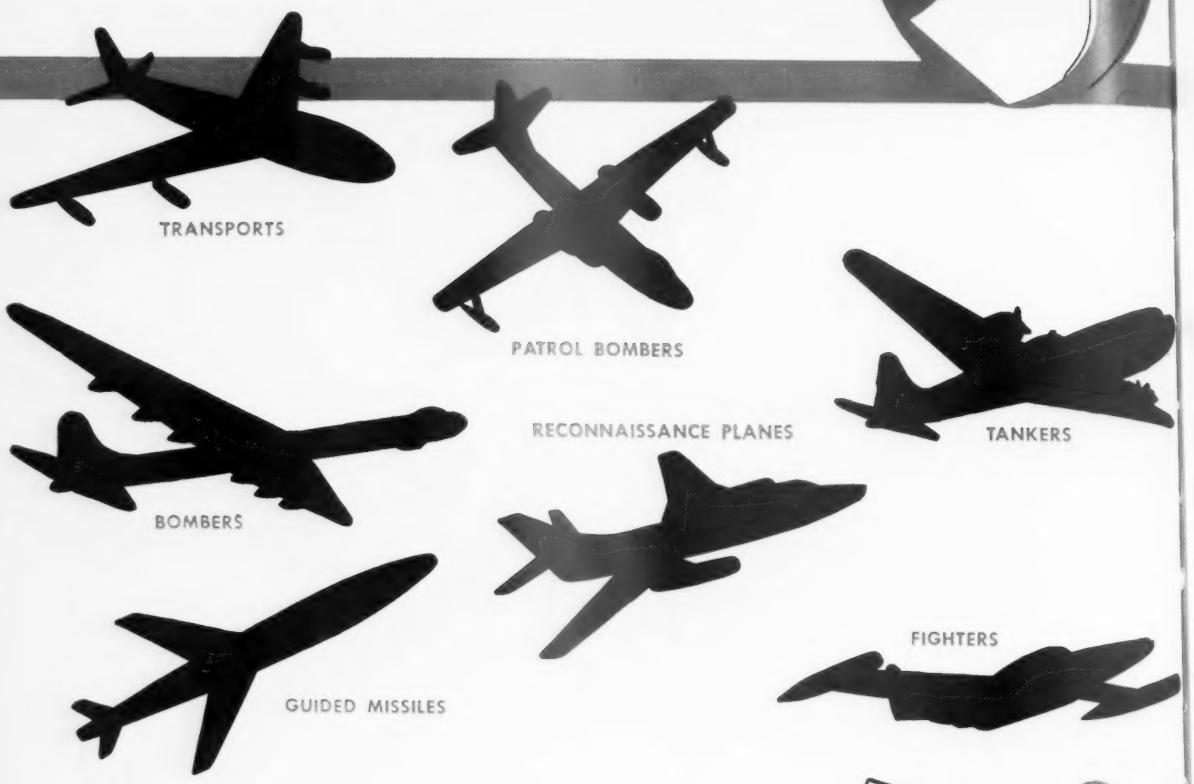
Aeronautical Engineering REVIEW

OCTOBER, 1954

Sundstrand
Constant Speed Drives
are now on all these types of aircraft . . .

SUNDSTRAND



Sundstrand Constant Speed Drives are used on all these types of aircraft because of the increasing need for constant frequency a-c power —power that is efficient, versatile, capable under all conditions. The Sundstrand Drive makes possible a completely automatic, parallel, constant frequency a-c system which is . . .

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CONSTANT SPEED DRIVES • AIRCRAFT ACCESSORIES

Aeronautical Engineering REVIEW

Vol. 13—No. 10 October, 1954

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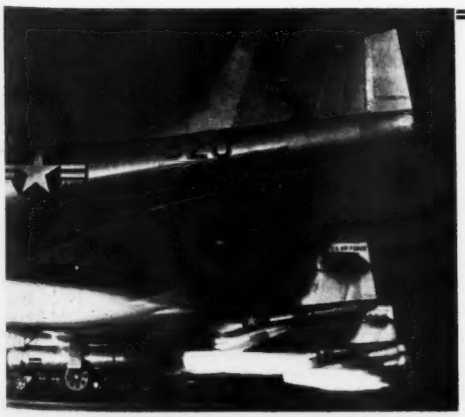

Cover—This night shot shows a group of F-89D Scorpions lined up on an apron and emitting streams of exhaust gases from the afterburner-equipped J-35-A-35 turbojet engines, built by the Allison Division of General Motors Corporation. The F-89D Scorpion is being built for the U.S. Air Force at the Hawthorne, Calif., plant of Northrop Aircraft, Inc.

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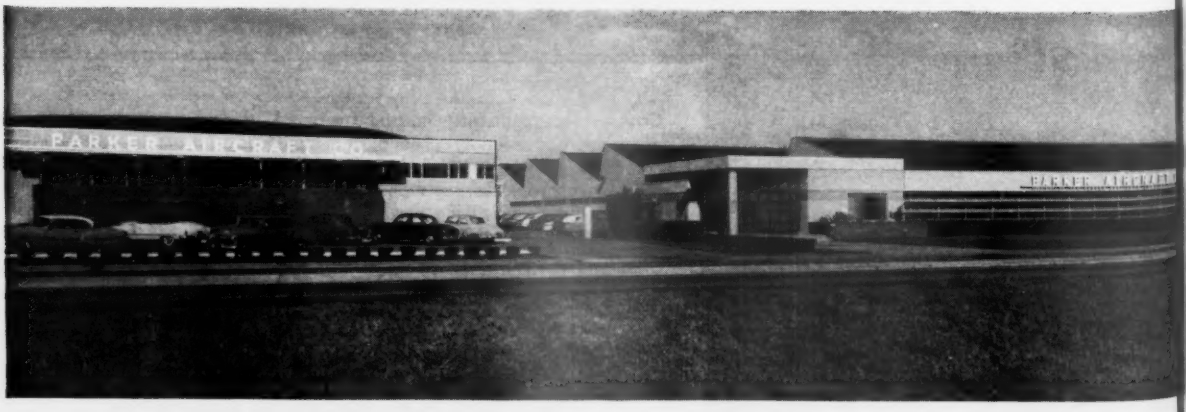

Send to Parker Aircraft Co. all inquiries for aircraft components. Both sales and engineering are now at this one location in Los Angeles . . . offering faster service. These modern manufacturing plants are next to the Los Angeles International Airport. Check valve plant is shown on the left, hydraulics and fuel products plant on the right.

I.A.S. News Notes

October 1954

AIR CARGO AND AIR LOGISTICS PROGRAM

The Institute of the Aeronautical Sciences is cooperating with the American Society of Mechanical Engineers and other engineering societies in presenting the Sixth Annual Air Cargo and Air Logistics Days Program. This Program, consisting of eight technical sessions, will be held during the ASME's Annual Meeting at New York City's Hotel Statler, November 29 to December 3.

* * * * * * * *

THE 1954 GUGGENHEIM MEDALIST

The Right Honorable Clarence Decatur Howe, Minister of Trade and Commerce and Minister of Defence Production, Canada, has been selected as the recipient of the Daniel Guggenheim Medal for 1954. The presentation will be made on October 8 during the Society of Automotive Engineer's National Aeronautics Meeting in Los Angeles. Mr. Howe is cited for "initiating and organizing commercial air routes and services, promoting aeronautical research, development and production of aircraft and engines, and advancing the art of aeronautics."

* * * * * * * *

IAS MEMBER HONORED

Arthur E. Raymond, HFIAS, Vice President--Engineering, Douglas Aircraft Company, Inc., will receive the Spirit of St. Louis Medal during the ASME's Annual Meeting. This award is given every 3 years for meritorious service in the advancement of aeronautics.

* * * * * * * *

NATIONAL MEETINGS CALENDAR

Oct. 14-15 - Joint meeting of the Canadian Aeronautical Institute and the IAS, Sheraton-Mount Royal Hotel, Montreal, Canada.

Dec. 17 - Eighteenth Wright Brothers Lecture, U. S. Chamber of Commerce Bldg. Auditorium, Washington, D. C. Bo Lundberg, Director, Aero. Research Institute of Sweden, Lecturer.

Dec. 20 - Eighteenth Wright Brothers Lecture (Repeated), Los Angeles.

Dec. 22 - Eighteenth Wright Brothers Lecture (Repeated), Cleveland.

Jan. 24-28- Twenty-Third Annual Meeting and Honors Night Dinner, Hotel Astor, New York.

March 11 - National Flight Propulsion Meeting (Restricted), Hotel Carter, Cleveland, Ohio.

June 21-24- Fifth International Aeronautical Conference, IAS Building, 7660 Beverly Blvd., Los Angeles, California.

* * * * * * * *

I.A.S. News Notes (con't.)

CALENDAR OF SECTION MEETINGS

Oct. 6--Chicago Section: Glenview Naval Air Station. Dinner Meeting, 6:30 p.m. "Potential Use of Cargo Helicopter" by Frank Piasecki, Chairman of the Board, Piasecki Helicopter Corp. Flight demonstration of Piasecki HUP helicopter.

Oct. 6--Philadelphia Section: Engineers Club. Dinner, 7:00 p.m.; Meeting, 8:00 p.m. "Recent Developments and Techniques in Carrier Operations." (Speaker unannounced.)

Oct. 11--Seattle Section: Sand Point Naval Air Station. Meeting, 8:15 p.m. "The Status and Problems of Air Safety" by Jerome Lederer, Flight Safety Foundation.

Oct. 12--Hagerstown Section: Packet Room, Terrace Restaurant. Meeting, 8:00 p.m. Speaker, F. D. Jewett, The Glenn L. Martin Co.

Oct. 12--Indianapolis Section: Meeting location unknown at press time. Speaker, Abe Silverstein, Associate Director, Lewis Flight Propulsion Laboratory, NACA.

Oct. 14--Los Angeles Section: IAS Building. Specialist Meeting, 7:30 p.m. "Flight Operations of the Mountain Wave Project" by Dr. Wolfgang B. Klemperer, Research Engineer, Douglas Aircraft Co., Inc.

Oct. 21--Dayton Section: Suttmiller's Restaurant. "Supersonic Accessories" by Frank E. Carroll, Jr., Chief Engineer, United Aircraft Products, Inc.

Oct. 23--St. Louis Section: Field trip to Dow Magnesium Company, Madison, Ill. 9:30 a.m. Plant tour followed by buffet luncheon.

Oct. 26--San Diego Section: IAS Building. Meeting, 8:00 p.m. "Biodynamics of Human Factors in Aviation" by Lt. Col. John P. Stapp, USAF (MC).

Oct. 28--Los Angeles Section: IAS Building. Social Hour, 6:00 p.m.; Dinner, 7:00 p.m.; Meeting, 8:15 p.m. "Information Theory" by Dr. Simon Ramo, Vice President and Executive Director, Ramo-Wooldridge Corporation.

Nov. 16--Dayton Section: Cordell's Supper Club, Fairborn, Ohio. "Aerobee Sounding Rocket" by Alfred B. Longyear, Aerojet-General Corp.

Dec. 9--Dayton Section: Plant tour of Aeroproducts Operations of Allison Division, General Motors Corporation, Vandalia, Ohio.

* * * * * * * *

NOTE OF INTEREST TO IAS MEMBERS

We thought you might be interested in knowing that the Institute's professional membership has passed the 10,000 mark this Summer. This is in addition to 3,000 Student Members.

* * * * * * * *

IAS News

A Record of People and Events of Interest to Institute Members

Tentative Program for CAI-IAS Meeting

Meeting to Be Held in Montreal October 14–15. Three Technical Sessions, Dinner, and Field Trip Scheduled.

THE NEWLY FORMED Canadian Aeronautical Institute and the Institute of the Aeronautical Sciences will hold an international meeting at the Sheraton-Mount Royal Hotel, Montreal, Canada, on October 14–15, 1954. This is the first joint meeting of the two societies since the CAI came into official existence on last February 6.

The program for the CAI-IAS meeting consists of a dinner on the evening of the first day, three technical sessions, and a plant inspection tour. Dr. Hugh L. Dryden, Director, NACA, is the principal dinner speaker, and will talk on "Aeronautical Research and the Art of Aircraft Design." Dr. J. J. Green, CAI President, Chief of Division "B," Defence Research Board, and Scientific Adviser to the Chief of the Air Staff, RCAF, Canada, will act as Toastmaster on this occasion. A reception, preceding the dinner, will begin at 6:00 p.m.; the dinner, itself, will start at 7:00 p.m. in the Sheraton Hall of the Sheraton-Mount Royal Hotel.

The three technical sessions will take place in the Normandie Room of the Sheraton-Mount Royal. They are scheduled for 9:00 a.m. and 2:00 p.m. on Thursday, October 14, and for 9:00 a.m. on the following day. The papers to be presented at these sessions and their authors are tentatively planned as follows:

Thursday morning session (Chairman, T. E. Stephenson, Director, Aircraft Branch, Department of Defence Production, Canada): "The Role of Fluid Mechanics on Aeronautical Development" by Dr. G. N. Patterson, Director, Institute of Aerophysics, and Head, Department of Aeronautical Engineering, University of Toronto, Canada; "Flying Techniques on Research Airplanes" by A. Scott Crossfield, Aeronautical Research Scientist, NACA High-Speed Flight Station, Edwards AFB, Calif.; and "The Nature and Stiffness of Swept-Wing Deformations with Reference to the Prediction of Normal Modes and Frequencies" by Albert H. Hall, Associate Research Officer, National Aeronautical Establishment of Canada.

Thursday afternoon session (Chairman, W. K. Ebel, Vice-President—Engineering, Canadair Limited): "The Orenda and the Future—Mechanical Design Considerations of Canada's First Production Turbojet" by B. A. Avery, Assistant Chief Design Engineer, Gas Turbine Division, A. V. Roe Canada Limited; "Bases Unlimited" by Ernest G. Stout, Staff Engineer, Convair-San Diego Division of General Dynamics Corporation; and "Production of an All-Weather Long-Range Jet Fighter" by R. K. Anderson, Assistant Industrial Engineering Manager, Aircraft Division, A. V. Roe Canada Limited.

Friday morning session (Chairman, G. R. McGregor, President, Trans-Canada Air Lines): "Air Traffic Control for Turbine Transports" by Charles W. Carmody, Chief, Operational Procedures Br., Airways Operations Division, CAA; "RCAF Training Operations" by Wing Commander C. H. Mussells, Commanding Officer, Central Flying School, RCAF, Trenton, Canada; and "Design Aspects of the Boeing Model 707" by Kenneth C. Gordon, Manager, Commercial Sales, Boeing Airplane Company.

Dr. J. J. Green, President, CAI

The field trip to the Montreal plant of Canadair Limited will get under way at 2:00 p.m. on Friday. It will include an inspection tour of Canadair's manufacturing facilities for the F-86 Sabre and the T-33 Silver Star aircraft.

This tour of the Canadair facilities may involve special arrangements for persons who are neither Canadian nor United States citizens. Those individuals in this category who are planning to attend have been requested to indicate this intention in a letter addressed to: A. E. Ainger, Public Relations Department, Canadair Limited, P.O. Box 6087, Montreal, Canada. Information on the writer's country of citizenship, his title or position, and his company or organization should be contained in the letter.

The programs giving the final details of this international meeting have been mailed to the CAI and IAS members.

Four IAS Members Among ION Executive

The Institute of Navigation recently announced the slate of 1954–1955 officers elected by ballot of the entire membership. Included among those elected to serve on the ION Council are Capt. D. B. MacDiarmid, USCG, MIAS, Coast Guard Air Station, Elizabeth City, N.C., and C. Towner French, AMIAS, Director of Military Sales, Fairchild Camera and Instrument Corporation. Captain MacDiarmid and Mr. French are Coast Guard and manufacturing representatives, respectively, on the ION Council.

Among the five Vice-Presidents appointed by the ION Council there are two IAS Founder Members: Ralph S. Damon, FIAS, President, Trans World Airlines, Inc.; and Sherman M. Fairchild, IAS Fellow and Benefactor, President and Chairman, Sherman Fairchild & Associates, Inc., and Chairman, Fairchild Camera and Instrument Corporation.

The President, Executive Secretary, and Treasurer for the 1954–1955 term of office are Major Gen. N. B. Harbold, Giles Greville Healey, and Keith F. Smith, respectively.

Israeli Aeronautical Engineers Form Society

Approximately 2 years ago, a group of aeronautical engineers living and working in the state of Israel founded the Israel Society of Aeronautical Sciences. This Society has a two-fold purpose: (1) to promote the development of aeronautical knowledge in Israel through the media of meetings, lectures, etc.; and (2) to set technical standards for members of the Israeli aeronautical profession.

Lectures on various aspects of the aeronautical sciences are presented at each meeting by ISAS members or distinguished visitors. The meetings are held monthly in the Lecture Hall of the Engineers and Architects Association in Tel-Aviv.

The present officials of the Israel Society of Aeronautical Sciences are: Chairman, Dr. Fidia J. Piattelli, AFIAS, Aeronautical Adviser, Design and Research Branch, Ministry of Defense, Government of Israel; Secretary, Capt. Iosef Singer, IAF, MIAS, Aeronautical Engineer; and Treasurer, Zeev Segal, Engineer in Charge, Reading Power Station, Tel-Aviv.

The mailing address of the Israel Society of Aeronautical Sciences is P.O.B. 2956, Tel-Aviv, Israel.

Necrology

Dr. A. F. Zahm

Dr. Albert Francis Zahm, IAS Fellow and Founder Member, died on July 23 at the Student Infirmary of the University of Notre Dame after a year's illness. He was 92 years old.

A native of New Lexington, Ohio, he matriculated at the University of Notre Dame where he received his baccalaureate degree in 1884 and his master's the following year. In 1892, he was granted a Master of Engineering degree by Cornell University. He received his Ph.D. from The Johns Hopkins University in 1898. Notre Dame granted him an LL.D. degree in 1917 and 8 years later singled him out for its highest honor, the Laetare Medal.

Dr. Zahm was a member of the Notre Dame faculty from 1885 to 1892, first as Professor of Mathematics and later as Professor of Mathematics and Mechanics. In 1895, he accepted the position of Professor of Mechanics at The Catholic University of America.

In 1893, he organized and served as Secretary of the International Conference on Aerial Navigation at the Columbian Exposition in Chicago. Around the turn of the century, he became Director of America's first full-sized wind-tunnel laboratory.

In 1915, Dr. Zahm was named Chief Research Engineer of Curtiss Aeroplane Company. Two years later, he accepted an appointment as Director of the U.S. Navy's Aerodynamic Laboratory. He left there in 1929 to become Chief of the Library of Congress' Division of Aeronautics, retiring in 1946.

Twenty years before the Wright brothers made their first flight at Kitty Hawk, Dr. Zahm—while still an undergraduate at Notre Dame—built a wind tunnel. A bit later, he built and flew gliders from the roof of the university's old Science Hall. At this period, he tested his theories of flight by suspending himself on a rope from the ceiling of the building and swinging back and forth across the room in his various contraptions.

News of Members

▸ **Dr. Ing. Giovanni P. Casiraghi** (AF) has accepted a post with the Brazilian government for the purpose of organizing an aeronautical training and research center at São Paulo. Dr. Casiraghi was formerly Chief Engineer, Aircraft Division, Piaggio & C. Societa per Azioni, Genoa, Italy.

▸ **Oscar W. Dillon, Jr.** (TM), Assistant Aeronautical Engineer, Cornell Aeronautical Laboratory, Inc., has been awarded one of the first three $2,000 fellowships for teaching and study at the Columbia University Institute of Air Flight Structures. The announcement of these fellowships and their winners was made jointly by Dr. John A. Krout, Vice-President and Provost of Columbia University, and Harry F. Guggenheim, IAS Honorary Member, Member, Benefactor, and Founder Member, President of the Daniel and Florence Guggenheim Foundation.

▸ **Professor Sydney Goldstein** (F), Chairman, Department of Aeronautical Engineering, Israel Institute of Technology (Technion), Haifa, Israel, will serve during the present 1954–1955 academic year as a Gordon McKay Visiting Lecturer at Harvard University. He is giving an undergraduate course in mechanics and an advanced course in hydrodynamics and aerodynamics. It was announced that Professor Goldstein has, at his own request, been relieved of his former duties as Vice-President of Technion so that he will be free to pursue his scientific work.

▸ **Sir Frederick Handley Page** (HF), Chairman and Managing Director, Handley Page, Ltd., was reappointed Treasurer of the Society of British Aircraft Constructors for 1954–1955. Sir Frederick, who is an Honorary Fellow of the Royal Aeronautical Society as well as of the IAS, was elected to this post at the June 23 meeting of the SBAC Council in London.

▸ **Dr. Paul E. Hemke** (AF), who was serving as Acting Chairman of the Engineering Group at Rensselaer Polytechnic Institute pending the selection of a permanent Chairman, has been succeeded in this position by Dr. V. Lawrence Parsegian. Dr. Hemke is Dean of the faculty at Rensselaer.

▸ **R. D. Hiscocks** (M), Senior Design Engineer, The de Havilland Aircraft

of Canada Ltd., was the first recipient of the McCurdy Award, presented on May 25 by the Canadian Aeronautical Institute. Mr. Hiscocks was cited for his work in the design and development of the National Research Council's tailless glider and for his contribution to the design of the Beaver and Otter aircraft. The trophy was presented to Mr. Hiscocks by the Hon. J. A. D. McCurdy, for whom the trophy was named.

▸ **Thomas C. Muse** (M), who was serving as Acting Secretary of the Coordinating Committee on Piloted Aircraft, has been named Secretary of this Committee as well as Secretary of the Coordinating Committee on Guided Missiles.

▸ **Mundy I. Peale** (AM), President, Republic Aviation Corporation, is one of 16 persons recently named to a USAF advisory group on small business. The function of this group is to suggest the best means of maintaining an adequate supporting structure of small business concerns under current and prospective conditions.

▸ **James D. Redding** (AF), formerly Executive Director of the Research and Development Board's Committee on Aeronautics, has been appointed Technical Assistant to Dr. Daniel P. Barnard, IAS Associate Fellow and Founder Member, Deputy Assistant Secretary of Defense (Research and Development). Mr. Redding is concerned with special technical projects of a broad nature which do not fall into the specific responsibilities of any particular coordinating committee. He is also serving as Deputy Member from the Research and Development secretariat on the Coordinating Committees on Piloted Aircraft and Guided Missiles.

▸ **Dr. A. E. Russell** (F), Director and Chief Designer, The Bristol Aeroplane Company Limited, England, was made a Commander of the Most Excellent Order of the British Empire (C.B.E.) in the Queen's Birthday Honours List, published last June.

▸ **Dr. Erich Schatzki** (M) is founder and head of Schatzki Engineering Company, Springfield Gardens, L.I., N.Y. While this company specializes in aeronautical design, it is also engaged in contractual research, design, development, and prototype manufacturing of electro-mechanical systems and devices.

▸ **Stanley W. Smith** (AF), Chief Airplane Engineer, Bell Aircraft Corporation, was one of the American glider pilots participating in the world gliding championships held at Great Hucklow, Derbyshire, England, from July 20 to August 4.

Members on the Move

The purpose of this section is to provide information concerning the latest affiliations of IAS members. All members are, therefore, urged to notify the News Editor of changes as soon as they occur.

J. Norman Ball (M), Principal Research Engineer, Flight Research Department, Cornell Aeronautical Laboratory, Inc. Formerly, Aerodynamics Project Engineer, Chance Vought Aircraft, Inc.

Howard W. Barlow (AF), Director, Washington State Institute of Technology, Washington State College. Formerly, Dean of Engineering and Director, Engineering Experiment Station and Engineering Extension Service, Agricultural and Mechanical College of Texas.

Kenneth E. Barnes (M), Technical Contract Group Supervisor, Missile Systems Division, Lockheed Aircraft Corporation. Formerly, Specifications Engineer, Lockheed.

Frederick G. Blottner (TM), Staff Member, Experimental Aerodynamics Section, Sandia Corporation. Formerly, Graduate Student and Recipient, M.S. Degree in Applied Mechanics, Virginia Polytechnic Institute.

Mason H. Campbell (M), Product Planning Engineer, Product Planning and Marketing Research Sub-Section, Small Aircraft Engine Division, General Electric Company. Formerly, Preliminary Thermodynamics Design Engineer, Development Operation, Aircraft Gas Turbine Division, G-E.

Wayne D. Cannon (M), now Permanent Representative in South America, Lockheed Aircraft Corporation, Victoria Plaza Hotel, Montevideo, Uruguay.

Dr. Jacob P. Den Hartog (F), Head, Department of Mechanical Engineering, Massachusetts Institute of Technology. Formerly, Head, Division of Applied Mechanics, Department of Mechanical Engineering, M.I.T.

Isaac Greber (TM), with Chance Vought Aircraft, Inc. Formerly, Research Engineer, Research Department, United Aircraft Corporation.

Francis R. Hama (M), Assistant Research Professor, Institute for Fluid Dynamics and Applied Mathematics, University of Maryland. Formerly, Research Associate and Instructor, Iowa Institute of Hydraulic Research, State University of Iowa.

Shukry K. Ibrahim (M), now with Department of Aeronautical Engineering, University of Minnesota.

Jack L. Kirk (M), Technical Staff, Chief of Administration, Wichita Division, Boeing Airplane Company. Formerly, Technical Staff Coordinator, Boeing-Wichita.

Eugene L. Krasnoff (TM), now Research Engineer, Gas-Dynamics Section, Research Department, United Aircraft Corporation.

Edwin H. Krug (M), Head, Aerophysics Section, Grand Rapids Division, Lear Incorporated. Formerly, Project Aerophysics Engineer, Convair-Fort Worth Division of General Dynamics Corporation.

George S. Trimble, Jr., MIAS, has been elected Vice-President in charge of the recently created Advanced Design Department, The Glenn L. Martin Company. Mr. Trimble was formerly Chief Design Development Engineer at Martin. The department that he heads is conducting studies in pure science for the purpose of opening new areas of activity for the Martin company. These fields of study include gravity, nucleonics, rocketry, and space flight.

E. V. Laitone (M), Professor of Mechanical Engineering, University of California, Berkeley, Calif. Formerly, Associate Professor of Mechanical Engineering, University of California.

Charles W. Lefever (M), Contracts Administrator and Director of Customer Relations, American Helicopter Division, Fairchild Engine and Airplane Corporation. Formerly, Vice-President, Prewitt Aircraft Company.

(*Continued on page 88*)

Dr. Shao Wen Yuan, AFIAS, formerly Associate Professor, has been promoted to the rank of Research Professor in the Department of Aeronautical Engineering, Polytechnic Institute of Brooklyn. Dr. Yuan, who has been with Brooklyn Poly since 1945, developed the first regularly offered courses in helicopters in an American engineering college. Born in Shanghai, China, he holds degrees from the University of Michigan, Stanford University, and California Institute of Technology.

Guest Editorial

UP and DOWN and ROUND and ROUND*

A Review of Reciprocating-Engine and Gas-Turbine History

By

Leonard S. Hobbs

Vice President—Engineering
United Aircraft Corporation

Courtesy John Haley

AVIATION BEGAN with the piston or reciprocating internal combustion engine, and it was this engine type that made controlled duration flight possible. Although man certainly would have flown eventually with some other type of prime mover, there is some doubt that without it the art would have gotten much beyond the curiosity stage for a long, long time.

The fundamental reason for its original and continued use is simple: Then and for about 40 years, this engine provided, in combination with the propeller, the most pounds of thrust per pound of engine and fuel weight possible to obtain. All of this occurred despite the fact that the turbine conception and, if history is to be believed, demonstration preceded that of the reciprocating engine by an extremely lengthy period.

Now it seems to me that this lag in the minds of men with regard to the piston engine was natural. If you can mentally transpose yourself into someone who had never known an internal combustion reciprocating engine, I think you will agree that it must have taken people with either little imagination or great faith to believe they could make such a thing work. In the first place, it is not possible to prepare a charge in the most perfect condition for instantaneous combustion and then poke it into a chamber filled to overflowing with swirling flame at 2,000° or more and not have it catch fire. And then to further believe that you can keep it there with nothing happening until the exact time within a few millionths of a second that you wish it to ignite is the ultimate of faith. At least so it seems to me.

The first suggestions for the piston engine seem to have originated in the 17th century and mostly revolved around the use of gunpowder as fuel. They were all apparently forgotten with the advent of steam and nothing happened until the very end of the 18th century. In 1794 in England, Robert Street patented an internal combustion reciprocating engine. Nothing usable came of it, but there is an almost continuous record of succeeding work, a great deal of which was done in this country. The culmination came in 1860 in Paris and was brought about by a transplanted Belgian, René Lenoir. This was a year before our great Civil War began. Lenoir is credited with adding nothing to the art or theory, and the only thing that I can find that he did was the one thing that really counted—he built engines that would operate. There is little doubt that in a general sense he is the real father of the modern piston engine. He produced and marketed several hundred engines of varying models running up to 20 hp., and their successful operation started great activity everywhere. Otto's work began with the refinement

* Excerpts from an address given at the National Turbine-Powered Air Transportation Meeting, IAS, Hotel Benjamin Franklin, Seattle, Wash., August 10, 1954.

of one of Lenoir's actual products, and Diesel got his early training on an Otto cycle unit.

From here on, it was a matter of gradual development, with the Wright brothers taking the state of the art of their time and competently adapting it to their special purpose. Following the Wrights there were many, many inventors and even more engines. As Igor Sikorsky remarked one time with reference to the helicopter, it was to the great good fortune of some of the inventors that their creations would not fly. But also many of these creations were ingenious and of solid worth. The remarkable thing is that between the Wright brothers and World War I, a matter of only 10 years, there was tried out just about every general type of piston engine that has been successfully utilized up to this time—air-cooled, liquid-cooled, banks, vees, radials, and that other impossible contraption, the rotary.

As you know, in the rotary engine, the cylinders, valves, piston, rods, and almost everything except the crankshaft rotate. I previously remarked on what I have conceived to be the qualities that must have been present in any individual to have caused him to believe he could make an explosion engine work. I can only characterize the pioneer of the rotary as a brave man. Yet at one time this arrangement represented the most advanced and, from an overall utility standpoint, the best engine. It combined the economy of material of the radial construction with a form of forced draft cooling, even though the latter was not very uniform.

Finally, there existed in this fruitful 10-year period an 8-cylinder REP engine that, although there are some basic differences, looks remarkably like a sizable segment of the Wasp Major—probably the largest piston-type aviation power plant that will ever be put into production. Most of what were then the unique designs, but which eventually reached some usable state, were of Italian, French, and English origin, although there was considerable experimental work in this country, particularly on the static radial. The Manley engine that actually preceded the Wright brothers' effort was a creditable engine of this kind and well engineered for its day, but it, of course, never advanced beyond the experimental stage.

As World War I opened, there were in operation essentially every known type and form of engine. As the war progressed, preference swayed from air-cooled to liquid-cooled and at least partially back to air-cooled again. Great progress generally was made in power plants with two or three individual items and innovations being outstanding. The German 6-cylinder in-line BMW based on the "over-dimensioned, over-compressed" theory was, as far as I know, the first real service use of an engine designed to overcome the normal reduction of power with altitude of the naturally aspirated engine.

Essentially all subsequent power regaining arrangements have been based on the use of some type of supercharger, but the German scheme did not incorporate this in any form. The compression ratio was made much higher than could be utilized at sea level, the displacement considerably greater than was normal for the engine frame and weight, and then there was applied what was, in effect, an oversized carburetor. The throttle could not be opened at sea level without disastrous results but was gradually opened as the altitude increased. The equivalent of 6,000 to 8,000 ft. of supercharging was obtained, which was not a negligible figure for those days.

Although one U.S. Air Force history credits the Fokker airplane with this engine as being the best of all fighters of World War I, the engine was not a complete success, I am told by some of the participants in the fighting. The Germans had come to realize the value of benzol as an antiknock agent in fuel, and it was used; but it was still far from being enough to care for this ambitious design so that full throttle operation still could not be tolerated at anywhere near sea level. The Allied pilots became aware of this weakness and would use ground level for evasion tactics or force the Germans to fight at the lower altitudes. True superchargers, which in the end became the single greatest factor responsible for increasing the output of the piston engine, were being worked on at this time—the turbo type by Rateau in France and the gear-driven at the Royal Aircraft Establishment in England. Somewhat later than Rateau, I think, Sanford Moss did the first pioneer work in this country on the exhaust turbine-driven type, and, in view of this later start, it is a rather contradictory turn of events that had us produce in this country the only units to see broad service.

The modern form of liquid-cooled vee engine was pretty well evolved and fixed in this period. The outstanding example was Birkit's French Hispano, probably overall the most valuable engine of the war and in retrospect somewhat of a work of genius in that it incorporated just about all the features of a present-day 8-cylinder vee except the twisted crankshaft that was necessary to eliminate the inevitable 4-cylinder couple. One that never saw service was the English Napier Lion, a 12-cylinder water-cooled "W" or broad arrow of extremely advanced conception and with an excellent fuel consumption. The U.S. Liberty engine of Vincent and Hall was not entirely representative of modern liquid-cooled development, and its history is not quite what the newspaper stories record. However, the accomplishment of its design and subsequent production was about as close to a miracle as is possible in this business and is an excellent example of what can be accomplished by a small competent team with no red tape or routine specifications to meet. In the light of some of our present-day schedules, it is something to consider. The engine was first designed and built as an 8-cylinder unit and only later changed to 12 cylinders. Yet, with the initial phases of the 8-cylinder design not getting started until the end of May, 1917, the first flight of the 12-cylinder version in a production airplane was made in October of 1917, and by November 11, 1918, 13,000 engines had been produced.

In the years immediately after World War I, the outstanding liquid-cooled engine was Arthur Nutt's D-12,

and there is little doubt that it was the best of this type in the world for a considerable time. It was imported into England in production quantities and had considerable effect on the subsequent liquid-cooled developments there. About all it lacked in basic design features to be representative of the best of World War II engines was a supercharger.

Finally, the modern form of the static air-cooled radial, which was destined to take over the vast bulk of the military and, essentially, all of the transport market of the world, got its start in this period, although it did not actually become available until 4 or 5 years after World War I was over.

Although the attainment of the air-cooled radial's ultimate position was inevitable, the particular spark that seems to have touched off the development of the modern version was the experimenting and push of a bold and determined American individual named John W. Smith, still alive and prospering. During the war, he obtained a contract from the British government for two engines of 150 hp., built them completely in a small machine shop, and carted them off to England for demonstration purposes. Although their design was most unorthodox by present-day standards, they ran well enough to convince the responsible British government officials that high powers could be obtained from this relatively simple and light type of construction. A specification was drawn up from which eventually came the Armstrong Siddeley "Jaguar" and the Bristol "Jupiter." These two engines can, I think, be called the true forerunners of the modern version of the general type of power plant that has pretty much represented aviation for over a generation.

In this country, Charles Lawrance, working first from Italian designs and later from his own, was the postwar air-cooled radial pioneer. However, it was the work of S. D. Heron that did as much as, if not more than, anything else to convince the skeptics. Heron was an Englishman who had worked with Professor A. H. Gibson, probably the first individual to attempt a scientific study and development of the air-cooled cylinder.

Heron, mostly by simple, single-cylinder work, demonstrated that power outputs comparable to those of the liquid-cooled engine of those days were entirely feasible. From there on, the air-cooled radial gradually took over despite the efforts of the same religiously partisan Heron, later turned traitor and helping to revive the liquid-cooled vee with high-temperature cooling. There have been many fine examples produced, but the best have been those developed out of the designs of George Mead and Phil Taylor which have dominated not only in this country but in much of the rest of the world.

There was little fundamental or unique added to the piston engine from this time on through World War II to the present. Acceptable engines of 28 cylinders were introduced. The exhaust-driven turbine was made practical as a source of power for the supercharger and later hooked up to the main engine as a power feedback. The period was one of great refinement, as well as improvement, in both gross and specific performance. It was over this time that we learned how to develop genuinely reliable operation, which, judged by ultimate effect, probably represents the most major advance of all.

And so, for 50 years the piston engine came along and made history. There seems something fundamentally wrong with the idea of incorporating an explosion engine in the lightest and flimsiest useful structure it is possible to build, and yet it has been a hardy old soul and has refused to be displaced overnight. Now it seems that the inevitable is finally happening. Before burial, however, it is worth taking a look at just one of its accomplishments, its 1953 transport performance. We have seen two world wars, in one of which at least aviation took a major if not predominant part, but it still could happen that the transport phase will overall be regarded in the end as our finest contribution. Omitting entirely all flying by nonscheduled and military transport or executive airplanes, the scheduled air lines of the world hauled 52 million passengers, an average of 540 miles apiece in that year, or a total of 28 billion passenger miles. I will leave it to the statistical minded to figure out how many pistons went up and down how many times or how many valves were opened and closed. I will only say in summing up on the piston engine that Robert Street and René Lenoir were men of vision and contribution.

There is something of a paradox that exists in the replacement that is now taking place—and in a way more romance. The paradox lies of course in the fact that the turbine is the older form of engine. Almost anyone can tell you of Hero's invention and its age. . . . What Hero did was to design a prime mover to accomplish a useful purpose, or at least one that was at that time considered useful, and it worked. The rotating part was a cylinder around which was fastened a rope. From this cylinder or drum the rope went through a sheave, then split into two parts, and these two, after going through various sheaves, were fastened to the two main front doors of a temple. When the turbine turned over, the rope was wound onto the drum and the doors were pulled open. . . . It seems to me in passing that this whole incident is somehow generally representative of the performance of a good engineer. Now Hero could have gotten a couple of bright and trustworthy youngsters, hidden them up above the doors, and saved himself a lot of work. But he really could not do that because, first, as an engineer with an engineer's principles, he had to be reasonably honest. Secondly, there was always the possibility that youngsters might talk, and then just where would the Administration be? Finally, I suppose he also figured it good business to keep his bosses impressed. However, I really do believe it a great pity that Hero attained success so quickly in life. His other work reinforces the clear indication of his genius, and, under the right circumstances, he possibly would have been

greater than da Vinci. But he was made a vice-president too soon and thus spent the vast majority of what should have been his productive years on politics and selling.

You will remember I noted that the first clearly indicated conception of a workable internal combustion engine was disclosed in a patent granted in 1794. Again the paradox appears. In 1791, or just 3 years previously, there was granted to John Barber of England a patent on a crude form of gas turbine.

There is not much concerning both aviation and jet propulsion from then until 1908. In that year a Frenchman, René Lorin, suggested that the exhaust of the piston engine as a jet could be utilized to sustain and propel an airplane. Nothing came of this for obvious reasons, but in 1921, which is getting fairly close, another Frenchman, M. Guillame, in a patent application made a disclosure of the modern form of gas-turbine jet propulsion.

Whittle started about 1929, and there is little doubt that he was the first of the pioneers who are responsible for the availability of the modern form of gas-turbine aircraft propulsion. Judged by the standards once set up by a venerated federal judge to define a valid invention—that is, the "flash of genius" theory—he comes the closest to meeting the test.

He is quoted as saying that, after he first completely worked out the theory of jet propulsion utilizing the gas turbine and knew what could be done, the only possible practical use he could foresee for it was a high-speed and very high-altitude mail plane to operate across the Atlantic. The altitude was to be between 40,000 and 50,000 ft., a remarkably accurate calculation of the technical phase even though his idea of commercial utilization at first was wide of the mark. Whittle deserves great credit not only for his pioneering but just as much in my opinion for his courage and persistence in carrying on against most formidable obstacles.

The two Germans, Von Ohain and Wagner, commenced work considerably after Whittle—that is, right around the very first of the year 1935. Although starting at almost exactly the same time, their efforts were entirely independent. They both seem to have been sparked into action initially by no theoretical consideration of reaction propulsion, but by the practical urge of finding something to make an airplane move faster than they could figure would ever be attainable by means of the then standard piston engine. Perhaps the judge would not agree, but I am inclined to think that possibly this "less-genius-but-more-cause-and-effect" circumstance is at least one reason why the Germans, starting later, flew first and also had the first production jet-powered airplanes.

Neither Whittle nor the Germans knew what the others were doing; in fact, Whittle did not know of the French patent of 1921, and there is a story in how and why they chose their design features. Whittle's approach was extremely simple and, I feel sure, the correct one under the circumstances. He realized he had a tremendous job ahead and therefore concentrated on employing as few unknown elements as possible. This of course led him directly to the centrifugal compressor about which a great deal was known, although it was far from being perfected at the time he started. The Germans on the other hand, with the idea of airplane speed uppermost in their minds, chose the axial flow because of its smaller frontal area. Thus, they set for themselves a much more difficult task and one that was not necessary because, although their thinking was good, their timing was not. The immediate postwar world speed record—and one that stood for a considerable period—was set up in England by the Meteor with two relatively large diameter centrifugal engines in the wings.

I am omitting the rocket and the ram-jet. In passing, however, I think it is an interesting commentary that these two things probably represent the oldest and newest forms of propulsion and in time completely bracket what has been discussed. There seems little doubt that the rocket was the earliest form of aerial propulsion, and, with nothing to go on but pure speculation, I would think the ram-jet conception would not have been evolved until speeds had reached some figure that would not require too much imagination to change them into pressure.

It is useless, I think, to speculate on either what would have happened had we been a little more enterprizing and had obtained gas-turbine propulsion sooner—I have stressed the evidence that shows that in conception it always antedated the piston engine—or where we are going to go and what we are going to do with it. Had the gas turbine been made usable before it was, it would not have done us much good in the form of jet propulsion. The first turbine jet-propelled airplane to fly could barely stagger through the air, and the first effort in this country, after all the help England gave us, had a top speed nearly 100 m.p.h. less than the best piston-engined airplane of that time. But, had we realized in 1920 what was attainable in a propeller turbine, or if there had existed the spur of a clear realization of just what a clean enough airplane would do with straight jet propulsion, history might have been different.

But difficult as it may be to say what might have been, it is relatively easy compared to seeing what is to be. I would not try. I am inclined to believe that concerning the really long-range future, we have barely scratched the surface, but also I would doubt that those responsible for the immensity of it will have any more fun that we have had.

Finally, I should like to disclaim any intention of attempting to judge the relative importance of events or of individual work through the period I have covered. I am certain that minor events have been recounted and magnified and major ones omitted. And, particularly, I realize that contributions of lasting worth have not even been considered and individuals responsible for directing the main stream not mentioned. I regret the omissions, but I have intended nothing but a sketch.

Report of Technical Sessions

1954 National Summer Meeting

By

R. G. Fuller*

Chairman, Program Committee

THE NATIONAL SUMMER MEETING of the Institute of the Aeronautical Sciences for 1954 convened in Los Angeles on Monday morning, June 21. During the ensuing 4 days, ten technical sessions were held under the direction of chairmen of national prominence in each of their respective fields. On Wednesday evening a banquet was given at the Statler Hotel featuring speeches by Donald W. Douglas, President of Douglas Aircraft Company, Inc., and H. H. Ogden, Vice-President—Manufacturing, Lockheed Aircraft Service, on the themes "Our Shrinking Globe" and the 30 years of global flying following the "First-Round-the-World-Flight" in 1924.

Thursday featured a field trip to Edwards Air Force Base, 100 miles north of Los Angeles on the Mojave Desert, where the IAS members were the guests of the Air Force and Brig. Gen. J. S. Holtoner and Richard Horner, Military and Civilian Directors of the Base.

The total attendance at the various activities of this meeting approached 3,500, and 39 papers were presented ranging in scope from "Transonic Testing Techniques" to "Aspects of Heavy Skin Construction."†

Accessory Design Problems

Homer Wood, Chairman
Engineering Consultant

John Hoch, Coordinator
AiResearch Manufacturing Company

The opening session was under the chairmanship of Homer Wood, who, in opening the session, pointed out the practical problems in this field and outlined the applicability of these papers to the problems. The following papers were presented:

(1) "Compressor Bleed in Turbine-Powered Aircraft" by B. L. Messinger, Department Manager—Thermodynamics, and W. W. Merrill, Jr., Group Engineer—Air Conditioning, Lockheed Aircraft Corp.

(2) "The Self-Contained Airplane" by Donald R. Elliott, Research Engineer, Boeing Airplane Company.

(3) "Thermal Considerations in Electrical Accessory Design" by E. W. Cornwall, Design Engineer, Douglas Aircraft Company, Inc.

Mr. Messinger presented the first paper. Mr. Merrill also was present and participated in the discussion. The first paper was largely an extended description and discussion of the current "state of the art" of the use of bleed air from turboprop and turbojet engines for aircraft auxiliary services. The evolutionary trend in the use of bleed air and the condition of that air at the bleed source were covered at some length. It was pointed out that the pressures and temperatures of this air are now such that the design of the ducting is a major structural problem. Examples were given of current practice. Of particular interest was a flexible joint that, by balancing pressures, eliminated ducting thrust loads. Another noteworthy disclosure was that of a new system of wing anti-icing which permitted the efficient use of high-temperature bleed air for this purpose without danger of structural damage to aluminum components. The plan made use of an ejector that recirculated air through a double skin for heat deicing. Mr. Messinger also tended to favor the use of direct bleed for cabin pressurization on the basis that current difficulties with bleed air contamination by lubricants would be eliminated in future developments. This paper also touched on the matter of providing a self-contained airplane through the use of gas turbine auxiliary engines. In particular, some form of engine that would convert to a "bleed-and-burn" turbine motor or air compressor using main engine bleed air for flight use would be preferred. In a general sense, the first paper tended to favor rather wide use of engine bleed air for air conditioning, deicing, and general auxiliary power service with, however, the proviso that careful consideration be given to the engine performance penalties in-

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† Most of the papers presented are being published in the REVIEW and JOURNAL. Preprints of papers available are listed on page 122 of this issue.

volved in each use. (This paper was published in full on page 50 of the September issue of the REVIEW.)

Mr. Elliott's paper covered at some length the desirability of providing a self-contained airplane for both military and commercial transport use. These advantages were regarded as particularly important for aircraft that did not have fixed base operation where ground facilities would be readily available. Even for fixed base operation it was felt that ground time would be minimized with important cost savings if self-containment were utilized. The paper emphasized the major advantages of engine bleed air in a coordinated low-pressure pneumatic power system and presented a particular pneumatic system as providing a self-contained airplane with little or no weight and performance penalty. It was the author's contention that the use of "bleed-and-burn" turbine motors would not involve undue installation and fire hazard problems and that they made the pneumatic system competitive with any other form of auxiliary power. Self-containment would be achieved through the use of a convertible gas turbine that would operate in flight as a pressurization compressor, driven by a "bleed-and-burn" turbine motor consuming engine bleed air. This plan presumed that contamination of main engine bleed would be such as to prohibit its use for air conditioning. In the event that such contamination would not be a factor, the auxiliary power gas turbine would represent some weight penalty for self-containment. (This paper was published in full on page 83 of the September issue of the REVIEW.)

The first two papers were discussed together because of their closely related nature. It was mentioned from the floor and confirmed by both speakers that noise level was a serious problem for air-borne auxiliary gas turbine installations. It was felt that substantial noise level reductions over those encountered with current unmuffled auxiliary gas turbines would be essential. Mr. Holzapfel of Western Airlines stated that he felt a weight penalty of 400 lbs. on a 145,000-lb. airplane would be quite acceptable as a penalty to obtain self-containment. In discussing system modifications to fit the case where bleed air contamination was not a problem, Mr. Elliott described another form of convertible gas turbine in which a clutch would be placed between the hot wheel and the compressor. This would permit the use of the hot turbine wheel as a "bleed-and-burn" motor to drive an alternator in flight, thus reducing the penalty for self-containment essentially to the weight of the compressor itself. Considerable discussion centered around the question of the seriousness of the bleed air problem. A representative of the U.S. Air Force pointed out that small fighter aircraft could not stand the weight and bulk penalties of equipment designed to overcome the contamination problem by pumping fresh air and that it was of great importance that the contamination itself be eliminated in the engine.

In the third paper Mr. Cornwall described the large weight penalties being paid to provide cooling for aircraft electrical accessories. To emphasize his point he used an airplane "growth factor" of 10 which indicated that each pound of excess weight due to poor electrical design would represent a production cost penalty of $400. This would justify large expenditures of funds to

Registration desk for Technical Sessions.

provide electrical equipment that both generated less heat and would be capable of rejecting that heat at higher temperatures. The author felt that insufficient exploitation had been made of high-temperature materials and that electrical equipment was poorly designed from a heat-transfer point of view as compared with normal heat exchangers. It was stated that the need was becoming critical for rapid development in these categories and that, unless the electrical manufacturers took such action, it would be forced upon the air-frame companies to do it themselves. Mr. Cornwall expressed the hope that this latter contingency could be avoided, although he showed examples of current activities of this sort in the Douglas organization.

In the discussion on the last paper several persons stated that a major obstacle to achieving the desired product improvements was the lack of adequate specifications against which manufacturers could bid. Since the design objectives were in general set by Government specifications, it is difficult to get manufacturers to undertake such programs, unless they are so required by these documents. The matter of conflicting objectives of standardization as against optimum equipment packaging for a specific airplane also involved considerable comment. It was suggested that standardization be applied to components of electrical-computor and power packages rather than the end-use packages themselves. It was noted that Ohio State University has published extensive research reports on the design of electrical components for higher temperature but that the industry seemed slow in using this information.

Electronics and Aircraft Electrical Systems

John R. Moore, Chairman
Assistant Director of Electrical Mechanical Engineering Department, North American Aviation, Inc.

Roy Jackson, Coordinator
Northrop Aircraft, Inc.

The afternoon session on Monday dealt with the Electronics and Aircraft Electrical Systems, with John R. Moore as chairman. The five papers presented explored this subject from the limits of "Practical Expectations and Limitations of the Reliability Problem," to "The Basis for Compromise Between Theoretical Performance and Operational Reliability."

The following papers were presented:

(1) "Practical Expectations and Limitations of the Reliability Problem" by R. H. Lindsay, Boeing Airplane Company.

(2) "Problems Encountered in Calculating Reliability" by Lucille F. Maier, Dynamics Engineer, Bell Aircraft Corporation.

(3) "A System for Recording and Analyzing Aircraft Flight Data" by R. E. Colander, Pacific Division, Bendix Aviation Corporation.

(4) "Magamps Applied to Aircraft Control Problems" by F. A. Baker and F. G. Timmel, Special Systems Section, Air Arm Division, Engineering, Westinghouse Electric Corporation.

(5) "The Basis for Compromise Between Theoretical Performance and Operational Reliability" by Wm. D. McGuigan, Head, Equipment Engineering Group, Stanford Research Institute.

Mr. Lindsay's paper, "Practical Expectations and Limitations of the Reliability Problem," discussed timely proposals, projects, and expedients which currently occupy the reliability picture. The subjects are classified into two groups, namely, short-range and long-range. In the short-range category, consideration is given to test-to-failure, 100 per cent testing of service units, development efforts on high failure rate components, and redundancy. In the long-range category, consideration is given to balance between initial and maintenance costs, simplification of design, failure information feedback, system planning, and coordination between widely separated organizations. Useful test-to-failure results are cited as being limited. The practice of sample testing is not questioned as the basis of acceptance or rejection of large batches of components merely for stock purposes, so long as it is understood that all units are subject to individual test before use. However, failure of a component to do its job properly is not the only situation; there are situations where improper design or environment calls upon a component to do more than it is intended to do. Each situation requires the careful consideration of the related factors of the reliability picture which is so essential to success. (This paper is published in full on page 65 of this issue.)

In a prepared comment H. Dean Voegtlen of Hughes Aircraft Company said, "Mr. Lindsay has faced the problem of reliability squarely. He has given us a clear picture of its size and complexity. I particularly like the broad view that Mr. Lindsay has taken, placing responsibility for reliability at each stage during the entire life of a piece of equipment. One problem certainly begins at initial design and extends through to the feedback and use of failure information from the field. We need to design our tests to duplicate service conditions. The fact that these conditions are never completely known should not invalidate the tests. To inspect and test each individual component, as it is delivered to the

manufacturer, is a highly unsatisfactory state of affairs. The only real hope of very high reliability lies in adequate design and well-controlled manufacturing operations."

Mr. Timmel gave the second paper, which was a good start in the field of presenting magnetic amplifiers as "black boxes," so that people not particularly concerned with the details of magnetic amplifier operation can begin to use them with more confidence. Mr. Timmel was talking exclusively about self-saturating magnetic amplifiers and presented three constants to describe these amplifiers. His concept of a gain constant is somewhat different and provides a clean-cut way of defining gain, although it is not necessarily in the terms in which it would finally be used. He described the transfer characteristics of the magnetic amplifier as a time delay—associated with the time delay between a resetting action of the control circuit and the output that results a half cycle or a cycle later in this type of magnetic amplifier—and a time "constant" —associated with the inductive delay in the control circuit. He presented several different typical self-saturating circuits and indicated applications of these.

Dr. D. P. Chandler of North American Aviation, Inc., in discussing Mr. Timmel's paper, pointed out that the doubler circuit that Mr. Timmel described has an additional time lag dictated by the load circuit, unless the output portion of the circuit is made inefficient powerwise by the addition of series resistors. Dr. Chandler also pointed out that the "dead-time" described by Mr. Timmel was not necessarily an ultimate limitation to the practical response of magnetic amplifiers, as Mr. Timmel had indicated, in that there are magnetic amplifier circuits (not of the self-saturating type) which do not have this dead time.

Mrs. Lucille F. Maier described the reliability program of the Bell Aircraft Corporation. The program is one of (a) close surveillance of the compounding of parts into systems, (b) analysis of surveillance data on parts, components, and system flights, and (c) incorporation of design and production changes (from data analysis) to enhance system reliability. Among the conclusions, the following are listed: (a) actual reliability data obtained from other companies are of doubtful value; and (b) reliabilities of parts, components systems, and missiles are most realistic if each is calculated individually rather than by a multiplication process.

In the fourth paper Mr. McGuigan presented an interesting theoretical speculation on basic relationships among factors such as theoretical system performance, complexity (in relation to numbers of components), average failure interval, time of operation, reliability, probable performance, and operational value. It is shown that increase in complexity in a given system involves corresponding increase in liability or debit values (due to additional weight, fuel, spare parts, man power, etc.) which may actually cause a negative operational value beyond a limiting value of complexity. Five curves are shown to illustrate the relationships discussed. The simplified general concepts presented by the author should be of interest to design and development personnel who seek the point of balance between theoretical performance and complexity which will assure that their products have maximum attainable operational value.

Messrs. Colander and Evans presented the last paper of the session. It was a somewhat detailed predevelopment concept of a system for simultaneous air-borne recording of 96 individual channels of flight-test data, with subsequent ground-based playback yielding outputs suitable for driving either analog recorders (such as conventional oscillographic and direct-writing recorders) or an IBM Model 701 Computer. The system provides for a maximum of 40 min. of integrated recording spread over an 8-hr. period. The overall system is expected to yield an accuracy of 3 per cent from transducer outputs to the digital record.

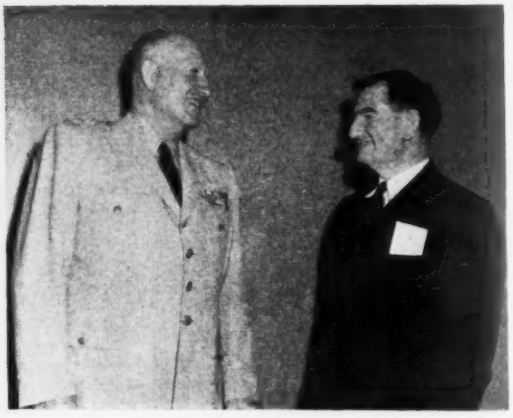
The air-borne recording system accepts data from various transducer types such as variable inductance, variable resistance, variable voltage, etc. Commutation technique is used to multiply the number of measurements which can be recorded. Transducer signals are used to frequency modulate low-frequency oscillators whose outputs are recorded. Air-borne equipment includes 4 separate tape recorders, each capable of recording up to 28 channels on a 2-in. wide magnetic tape. Tape speed is 10 in. per sec.; reel diameter is $10^1/_2$ in. Four of the 28 channels are used for time signals and control purposes. A programmed in-flight calibrator, operating at 1-min. intervals, provides the required calibration signals. The ground-based data reduction system includes a number of ingenious features that facilitate the performance of its functions.

Military Aircraft and Weapons Operations

Edgar Schmued, Chairman
Vice-President—Engineering, Northrop Aircraft, Inc.

Roy Jackson, Coordinator
Northrop Aircraft, Inc.

Mr. Schmued outlined the background of Major Gen. C. S. Irvine, Deputy Commander for Production,



Air Materiel Command, Wright-Patterson Air Force Base, who presented a paper on "Air Weapon Systems in Operation."

General Irvine pointed out that the complexity of the modern weapon system requires the collective effort of many skills, and this has led to numerous small independent groups working on individual problems without sufficient coordination. The Air Force desires, however, to achieve a balanced weapon system wherein all parts are essentially operationally equivalent. Technological developments during the last 15 years have fairly outpaced the machinery and personnel "know-how" of the Air Force to control and coordinate them. During this period, a pattern has been developing into the air weapon system concept having the following objectives:

(1) Separation of the research and development and production phases, with the investment of responsibility for each phase with separate groups.

(2) Planning for logistics, maintenance, service, and training under the Weapon System Procurement Office.

(3) Delegation of operational responsibility for the whole product package to the appropriate Air Force depot.

The Weapon System Procurement Office consists of a combined ARDC engineering and AMC procurement team working to control the necessary daily decisions and compromise inherent in any complex system. This group is periodically advised of Air Force thinking, war-plan changes, and supply, maintenance, and logistic aspects during monthly meetings with the representatives of AMC, APGC, ATRC, and Tactical Command Specialists wherein each individual is encouraged to acquaint all concerned with his particular problem.

Producing a weapon before the design is debugged often results in a major modification program. Returning weapons to the manufacturer for maintenance and overhaul assists in correcting design and deficiencies. Cycled maintenance common to air-frames and engines is mandatory for reliable operation of complex auxiliary systems and, in many cases, has required the creation of equipment phasing groups for control.

The Air Force, subject to Congressional action and changing world conditions, cannot operate "just like any other business" with plans formulated well in advance, desirable though this objective may be. A high degree of flexibility is required and obtained through delegation of authority well down the line. This concept must be compromised by the desire for standardization. Our objective is to give better service to the Air Force and industry throughout the life of a weapon system. In this regard, all jobs can be made easier if industry, at the earliest possible date, will take upon itself to provide a comprehensive list of items required to support its system.

The logical objective of a weapon system is a "low-level, fast-moving inventory, with a short turn-around time" and can be obtained only through a comprehensive, well-planned design and equipment program. We must discontinue the practice of designing aircraft that meet contractual performance with little regard to the problem of maintaining and servicing the system during a long operational life.

Operational Flight Problems

George Mellinger, Chairman
Chief of Flight Test, North American Aviation, Inc.

John Hoch, Coordinator
AiResearch Manufacturing Company

The Operational Flight Problems Session started the second day of the Summer Meeting with George Mellinger as its chairman. Three excellent papers covering the electric control of jet engines, turbine engine problems, and turbine-propeller engine application brought lively discussions from the floor.

The following papers were presented:

(1) "An Evaluation of an All-Electric Control System for a Jet Engine" by F. W. Preston, Supervisor of Installation and Service Engineering, and E. J. Specht, Aircraft Gas Turbine Specialist, General Electric Company.

(2) "Some Operational Problems of Turbine Engines" by Abe Silverstein, Associate Director, NACA, Lewis Flight Propulsion Laboratory.

(3) "Turbine-Propeller Engine Application to Transport Aircraft" by P. A. Colman, Chief Preliminary Design Engineer, Lockheed Aircraft Corporation.

Mr. Specht presented the first paper and pointed out that the advent of an all-electric jet-engine control was brought on with the afterburner engine installations on interceptor-type aircraft. An evaluation of the J-47-17 integrated electric control system for the F-86-D was presented. Mr. Specht covered several installation and service problems and their solutions encountered on the F-86-D. Based upon their past experience, the authors made recommendations for future installations.

Abe Silverstein presented an enlightening paper, "Some Operational Problems of Turbine Engines." Mr. Silverstein reviewed some of the current operational problems of turbine engine installations, briefly discussing the relationship between the engine design and engine operational problems. For flight at supersonic speeds, the author outlined and discussed problems of propulsion system installations. He particularly emphasized the need, in the early stages of the design, for consideration of compromises in performance which are required to obtain satisfactory propulsion system operation. A light touch was added to this talk when, during a film clip, a jet plane was found taxiing in reverse. The projectionist was finally put at ease when Mr. Silverstein explained that the airplane had a thrust reversal device installed.

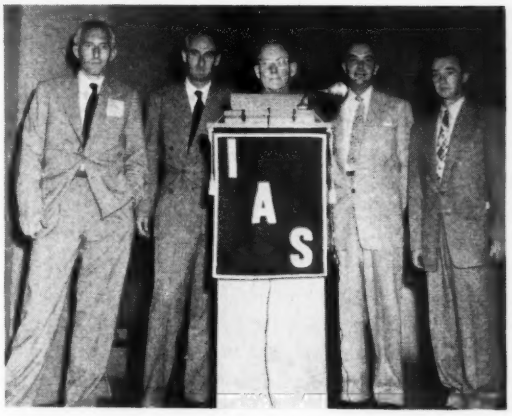
After intermission, P. A. Colman gave his paper entitled, "Turbine-Propeller Engine Application to Transport Aircraft." Mr. Colman presented a strong case for the turbine-propeller engine as the optimum type of power for transport airplane design predicated on (a) maximum economical operation for moderate ranges and (b) instances where speed is not a premium for attracting business. The turbine-propeller engines do not simplify a design, since they inherit most of the problems of the reciprocating and turbojet engines. The speaker recounted some of Lockheed's interesting solutions to engine control and safety problems on current designs.

Human Problems of Flight

Dr. John R. Poppen, Chairman
Consultant in Aviation Medicine, Douglas Aircraft Company, Inc.

Al Carah, Coordinator
Douglas Aircraft Company, Inc.

The Tuesday afternoon session was under the chairmanship of Dr. John R. Poppen. Contemplation of the scope of the subject made it immediately apparent that it could not be covered in the time allotted to the session. Nor was it practicable to present an outline.



It was agreed to focus attention on a few areas that could be considered as timely and of interest to those present.

On this basis it was decided to request presentations on the three topics listed below. In response to this request, the following papers were presented:

(1) "Designing the Cockpit for High-Speed Flight" by S. N. Roscoe, Hughes Aircraft Company.

(2) "Human Factors in Jet-Transport Design" by Frank C. Hale, Douglas Aircraft Company, Inc.

(3) "Man and Machine Between Atmosphere and Space" by Heinz Haber, Institute of Transportation and Traffic Engineering, University of California.

In "Designing the Cockpit for High-Speed Flight," S. N. Roscoe presented the problem in a clear light and combined an exploitation of what is needed to be done with an explanation of the promise of certain facts that he has already established. He pointed out the fallacy of answering the question of how to fly high performance aircraft simply by leaving out the human pilot. Men have certain capabilities that cannot be replaced by automatic equipment. "Instead of taking the men out of our airplanes, we must take maximum advantage of these marvelous abilities possessed by all normal people."

Dr. Roscoe described two examples of research which have proved that research into cockpit displays, controls, and automatic equipment results in improvement in the effectiveness and accuracy with which pilots can fly high performance aircraft. By concentrating on the "principle of the moving part" in combination with a judicious application of the principles of "quickening" the displays and "unburdening" the controls, he showed that learning curves can be significantly improved. What is perhaps even more striking in considering the problem of selecting and training pilots for our new aircraft is the fact "that the transition from an unnatural display and control-display relationship to a more natural display having a better relationship to the controls can result in almost 100 per cent transfer of training."

Dr. Roscoe's presentation permits little if any successful dispute of his conclusion: "In any event, we have little choice in the matter. The higher per-

formance of our modern airplanes requires higher performance from our pilots, and this cannot be attained with present cockpit displays and controls."

In discussing "Human Factors in Jet-Transport Design," Frank C. Hale emphasized the growing importance of human engineering and human factors in the design of aircraft. The particular area in which he illustrated this fact was his current interest in human problems as applied to the design of high performance jet transports. His position with the Human Engineering Group of Douglas Aircraft Company, Inc., Santa Monica Division, has presented a vantage point from which to learn at first hand how these factors must be considered as an integral part, along with aerodynamics and power considerations, in arriving at an adequate man-machine relationship for all types of aircraft.

Because of the progress in the design of high performance, high altitude transportation of passengers, his presentation was particularly timely. He illustrated this by recounting a fairly recent case in which a new design came off the production line with excellent aerodynamic characteristics but an unfortunate insufficiency of room provided for the crew. Such oversights are no longer to be expected with the increasing realization that the human factors are critical elements in the design of aircraft. (This paper is published in full on page 84 of this issue.)

From the problems of appropriate design of high performance aircraft that are currently flying and expected to fly in the immediate future to provide for effective utilization of human capabilities, it seemed logical to ask the next question, Where do we go from here? The program committee was particularly fortunate in securing the acceptance of an invitation to present a paper on "Man and Machine Between Atmosphere and Space" by the eminent authority, Dr. Heinz Haber. His wide experience and technical knowledge of the problems of travel in space qualify him to prepare and present a discussion of the human aspects of travel by airfoils from the atmosphere into the altitudes where aerial support is lacking and certain physical considerations introduce new and unproved problems.

For those interested in pursuing the subject further, Dr. Haber's bibliography is particularly well chosen and arranged in a sequential order for progressive improvement of knowledge of the subject. Dr. Haber does not gloss over potential threats to travel in space, but he does leave us with some comfort. His presentation is best read in its entirety to comprehend its true import; it would be futile to attempt a comprehensive review of it here. It is enough to quote his concluding paragraph:

"The human problems of flight in the aeropause—which constitutes the frontiers of flight in the next future—will differ from today's problems only by degree. The only exception is weightlessness, which will be a novel experience to air crews. Barring any undue surprise in man's ability to live and to perform under conditions of weightlessness, it appears that man will be ready to fly in the regions between atmosphere and space as soon as the engineer will furnish the machine that can do likewise."

After the formal presentation of these three papers and the opening discussion of each, the session was converted into an informal panel in which the speakers and their designated discussants entertained questions from the floor. This opened general discussion in which many of those attending the session took part. The discussion centered largely about the presentation of data and the newer philosophy of what cues were important and the improved methods of presenting them to the pilot. The relation of these factors to progressive travel to higher altitudes at greater speeds was discussed with a resultant concensus that the areas covered by the program represented timely and interesting subjects.

Aspects of Heavy Skin Construction

Leo Carter, Chairman
Vice-President, Douglas Aircraft Company, Inc.
Al Carah, Coordinator
Douglas Aircraft Company, Inc.

Three papers were presented Tuesday evening on the "Aspects of Heavy Skin Construction." These were:

(1) "Wing Design for Practical High-Speed Aircraft" by D. W. Finlay, Project Engineer—Jet Transport, Boeing Airplane Company.

(2) "Tooling Aspects of Heavy Skin Construction" by C. S. Glasgow, Chief Tool Engineer, Douglas Aircraft Company, Inc., Santa Monica Division.

(3) "Fabrication Aspects of Large Structural Components" by H. C. Schwalenberg, General Superintendent, North American Aviation, Inc.

The first paper by Mr. Finlay showed that airplanes originally designed about 15 years ago and continuously improved to increase performance and load-carrying ability are still in service today. Any new design must have the same life expectancy if it is to succeed. Redesign is necessary during the life span of each model, therefore, to achieve this continuous competitive improvement; this growth must be planned for carefully and wisely to avoid weight penalties in the initial airplane. Recognition of these probable future requirements and rate of production will have a profound effect upon the selection of the basic structure to be used.

There are three basic methods of construction available for a wing panel.

(a) Conventional riveted sheet and stringer construction has the advantage of familiarity gained through past projects, but the number of rivets and attendant problems involved in their use impose substantial cost.

(b) Extruded skin and integral stiffener construction gives some excellent shapes, but inadequate widths and problems of straightening and contour control present difficulties in its application.

(c) Skin and integral stiffeners machined from plate stock by removing the unwanted material between the stiffeners would reduce assembly man-hours considerably, but the development of adequate milling machines—as well as contour forming—presents an objection.

The selection of the method of construction depends upon the quantity involved and the rate of production. A construction having a break-even point after several years may never break even, even after the envisioned quantity has been exceeded, if the cost of model changes required along the way for competitive improvements eats up the margin of superiority.

In forming, also, these same considerations apply. Whether a block will be machined on Keller-type equipment, a rough forging machined to size, a die forging finish-machined on attaching points, or a low or zero draft forging installed directly will depend on the quantity required and the production rate.

The original design should, therefore, be selected so that future design changes may be accomplished expeditiously and at the lowest possible cost.

Mr. Glasgow dealt with "Tooling Aspects" of the present-day aircraft designs incorporating thick skins and requiring higher performance of the airfoil shapes and greater efficiency from the structural joints. In order to meet the requirements placed upon them by engineering design over the past 20 years, assembly tools have changed in their design. It may be said that there has been a shift in the responsibility for accuracy. In the early days of metal aircraft, the prime responsibility for external fairness and lack of skin waviness was upon the aircraft assembly mechanic. This responsibility shifted somewhat with the increased rates of production to where it was mainly placed upon the assembly tool and now, with heavy skin construction, has again shifted to where the fabricating or detail tool that shapes the heavy plates before they arrive at the assembly tool has the major responsibility in producing extremely smooth surfaces. With heavy skin construction today, waviness in the order of 0.010 of 1 in. in 10 in. is to be expected. If engineering design requires less waviness than this in the future, the external surfaces will have to be shaved to shape as a machine operation *after* assembly.

Heavy skin construction, with its tendency toward longer members, has also amplified the problem of the linear expansion. If further control and accuracy are required in lengthy assemblies, then here, again, machining by cutting to length after assembly with milling machine heads mounted on the assembly tool—particularly at its attaching joints—will be required.

In addition, heavy skin construction has greatly increased the cost and problem of making many close

tolerance holes for attachment purposes in these assemblies. If further accuracy is required, it will be obtained only through extremely close boring of holes, during assembly, with machine tools somewhat the type of the jig mill or jig borer.

Then it may be concluded that, to obtain closer tolerances of heavy skin construction, machining after assembly will be the solution.

The final paper by Mr. Schwalenberg pointed out that the advancement in design toward the use of large single-piece components, rather than the bits-and-pieces type of structure, has demanded new fabrication techniques to meet the requirements. Large die forgings, routed grids, and taper-milled or machine-sculptured plate are typical forms that might be employed in any future design.

The heavy press program for large precision die forgings is well under way, and presses of 35,000- and 50,000-ton capacity will be completed around the end of this year. The tremendous economies that may be realized by the use of precision forgings make it a proper subject for speculation. Parts may be designed possibly to be used as precision forgings when these presses are completed and may be made, meanwhile, by cavity milling on globs or neutral die forgings.

Routed grids are used primarily in outer wing panels and dive brake doors to distribute concentrated loads. Routed grids produce lighter weight parts than die forgings because of the elimination of draft and the closer tolerances that are maintained. A cost analysis also revealed them to be superior to hat section stringers, straps, and doublers.

The contouring of routed grids has been most successfully accomplished by the form die quench process, in which the heat-treated part is formed, while hot, in closely mated forming dies. The dies act as the quenching medium on smaller parts by thermal conductivity; on larger parts, the dies are cooled by circulating water through cored-out cavities.

Taper-milled or machine-sculptured plate has also been used successfully. Initially, this process was used only because of possible weight-saving in com-

parison to a built-up assembly, but now it may be justified on a cost basis also.

From flat tapered-skin milling has developed sculptured milling of integral ribs and stiffeners. This has proved to be best structurally as well as costwise for production quantities. Forming of these parts requires a new technique, however, because of the limitations of size in the die quench method. Prestressed hot forming has been used successfully wherein the parts are overcontoured in a fixture, heated to a controlled temperature in the precipitation aging range, removed from the oven, and quenched in the fixture by water spray.

Future problems, combined with present problems that are not as yet completely solved, point to need for exploration and development if we hope to maintain a production pace equal to design progress.

Aerodynamics

Dr. Clark B. Millikan, Chairman
Director, Guggenheim Aeronautical Laboratory

Leo Celniker, Coordinator
Lockheed Aircraft Corporation

The selection of four papers from over 30 submitted for presentation at the Wednesday morning session proved a formidable task, which, however, was made somewhat more manageable by the objective of a logical pattern for the complete session. The pattern finally chosen included the following elements: All the papers dealt with problems raised by the recent development of practical and even routine supersonic flight; all were primarily concerned with nonlinear effects for which the classical small-perturbation, linearizing techniques are inadequate; and the speed range covered by the successive papers increased continuously as the session proceeded.

The following papers were presented:

(1) "Experimental Investigation of Influence of Edge Shape on the Aerodynamic Characteristics of Low-Aspect Ratio Wings at Low Speeds" by G. E. Bartlett and R. J. Vidal, Aerodynamic Research Department, Cornell Aeronautical Laboratory, Inc.

(2) "Transonic Limits of Linearized Theory" by J. D. Cole, California Institute of Technology.

(3) "Stability of Compressible Laminar Boundary Layer with Internal Heat Sources or Sinks" by G. M. Low, NACA, Lewis Flight Propulsion Laboratory.

(4) "The Generalized Shock-Expansion Method and Its Application to Bodies Traveling at High Supersonic Air Speeds" by A. J. Eggers, Jr., Raymond C. Savin, and Clarence A. Syvertson, NACA, Ames Aeronautical Laboratory.

The program was opened with Mr. Bartlett's paper, which covered an extensive experimental investigation at low speeds of a family of low-aspect ratio wings whose shapes are appropriate for supersonic flight. The primary consideration was the effect of wing-edge variations on lift, stability, and control. Satisfactory correlation with semiempirical theory was obtained. It was pointed out in the discussion that there was no real "theoretical" basis for the formulas used and that their chief virtue was that they were simple and seemed adequately to describe the experimentally observed phenomena.

The session then continued with a discussion of some transonic questions raised in a paper by Prof. J. D. Cole. Notwithstanding its title, the paper dealt with nonlinear effects or, at least, with a determination of the conditions under which they must be considered. The author presented the results of calculations which showed that for thin figures of revolution, accelerating through sonic speed, the nonlinear terms can be neglected if the acceleration is large enough. During the discussion, Professor Miles of University of California at Los Angeles pointed out that the phenomena are different for acceleration and deceleration through the speed of sound.

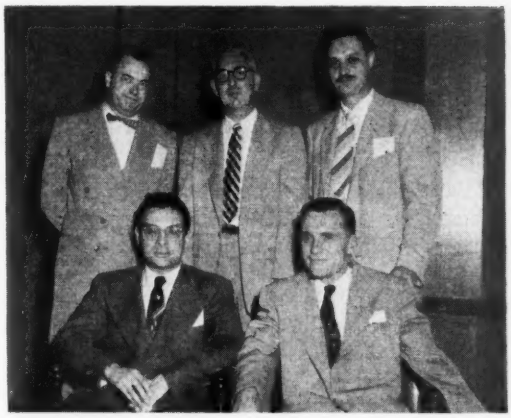
The next author, G. M. Low of the NACA Lewis Laboratory, considered boundary-layer effects associated with variations in density in the presence of heat addition and removal. These effects exist even at subsonic speeds but become important primarily at moderate to high supersonic speeds. The paper was entitled "Stability of Compressible Laminar Boundary Layer with Internal Heat Sources or Sinks" and involved a discussion of boundary-layer stability and surface cooling.

The final paper by A. J. Eggers, Jr., Raymond C. Savin, and Clarence A. Syvertson, all of the NACA Ames Laboratory, entered the hypersonic flow region. Eggers, who presented the paper, gave a relatively simple, approximate method of dealing with certain aspects of the extremely complex problem of flight at high supersonic speeds and justified the procedures by comparing calculated results with experimental data. The paper was followed by the most spirited discussion of the morning, which ended on the highly satisfactory note that further argument would be engaged in after the close of the formal session.

Structures

Jerome F. McBrearty, Chairman
Chief Structures Engineer, Lockheed Aircraft Corporation

Rolf Buhler, Coordinator
Propulsion Research, Inc.



The Structures Session was somewhat of an experiment. Instead of the presentation of papers on structural developments (and many important developments merit presentation), the entire session was devoted to stimulating papers on structural design philosophy or policy. One of the most controversial and yet fundamental aspects of structural design philosophy is the question of designing the aircraft structure by means of a technique that has become known as the "stretch method." It is rather generally the experience in structural design that much, if not all, of the structure turns out to be stronger than the designer or stress engineer intended, and the stretch method is patterned to exploit this overstrength, in order to minimize structural weight, by deliberately designing to a lower "target" strength and then reinforcing those spots that need more strength in the airplane static tests.

L. M. Hitchcock, Structures Staff Engineer, Boeing Airplane Company, Seattle, presented "Development of Optimum Structure for Large Aircraft," which was a lucid and convincing discourse on the arguments against this method, at least for large aircraft. Mr. Hitchcock advocated a philosophy of designing large aircraft, at least, to 100 per cent of required strength, instead of an initially lower target, on the basis that this method results in lightweight structure, assures reasonably prompt completion of the static test, provides maximum production continuity, and necessitates a minimum of restrictions in early flight tests. Utilization of the target weight-control system, liberal static testing of parts of the structure, and a careful stress analysis tempered with experience on past designs result in a lightweight structure designed initially to 100 per cent of required loads, according to Mr. Hitchcock. Even with this design approach, the static tests are seldom trouble-free, but the stretch method would result in an even greater number of early failures in test which hamper production continuity and entail prolonged testing and flight-test restrictions. It has been Mr. Hitchcock's experience, also, that the latent strength of the structure is exploited anyway in subsequent versions of the basic model.

John H. Meyer, Chief of Structures, Airplane Engineering Division, McDonnell Aircraft Corporation, made a strong case for the stretch method in "Test Development of Structures Designed Understrength." Mr. Meyer brought out forcibly the importance of saving weight and the impact of this saving on the airplane performance. He reviewed the record of USAF static test failures below 100 per cent ultimate and attributed this in a most convincing fashion to the lack of precision in analytical methods, to the important contribution of "unstressed" structure, to the "idealizing" of structure that is far from ideal, and to the nonlinear behavior of the structure invariably assumed linear. Some typical comparisons of measured versus calculated internal stresses demonstrated the very real departure of the structure from the stress analysis. Mr. Meyer presented the results of the stretch method applied to one series of a fighter airplane, and, while not without sweat and pain, an important weight-saving was attributable to this design philosophy. Specifically, Mr. Meyer recommended designing for 15 per cent understrength, with full account made for aeroelastic and fatigue effects and uncompromised design loads, as a valuable tool in developing efficient aircraft. (This paper is published in full on page 54 of this issue.)

No less fundamental or controversial in the realm of structural design philosophy is the necessary magnitude of the structural factor of safety—the amount by which the ultimate strength of the structure shall exceed the expected loads. George N. Mangurian, Chief of Structures, Northrop Aircraft, Inc., made a challenging presentation on this subject in "Is the Present Aircraft Structural Factor of Safety Realistic?" Mr. Mangurian traced some of the early thinking that resulted in the current value of 1.50 and which has become almost traditional. This research revealed that the most important elements for which the factor of safety must provide are: no yielding under service (or limit) loads, allowance for material and workmanship defects, allowance for design uncertainties and inaccuracies, and allowance for rigidity and occasional exceeding of specified maneuvers.

Taking up these elements one by one, Mr. Mangurian showed clearly, and with splendid color slides, how the situation has changed since the factor of safety was originally chosen. The change in material yield to ultimate ratio, the great strides in inspection techniques and analytical methods, and other considerations indicated that a critical look at the safety factor was indeed in order. Furthermore, the popular concept that the present safety factor provides the

pilot with a uniform 50 per cent margin above his operating restrictions was shown to be erroneous because of the nonaffined relationship between the load levels of various components of the structure, such as the wing and tail, and the dissimilar effects of up and down gusts, for example.

Mr. Mangurian then showed some attractive effects of reducing the safety factor and the benefits of the attendant weight-saving on the performance capabilities of sample aircraft. In conclusion, he recommended classifying the structures into two categories, A and B.

In category A, for which the safety factor would remain as it is, would be structures with uncertain loads and load distributions, structures affected by operating limits easily exceeded, and those where phenomena like aerodynamic heating cannot be accurately determined. He recommends that a reduced safety factor be considered, however, for category B. This class includes structures where loads are physically limited, such as ram pressures and absolute vacuum pressures, and those where loads are limited by reliable devices and by important aerodynamic maxima. (This paper was published in full on page 63 of the September issue of the REVIEW.)

Since these three papers had a common denominator—i.e., structure design philosophy—comments were held in abeyance until all three authors were heard. At that point, G. G. Green, Chief Structures Engineer, Convair, San Diego, presented prepared comment on the three papers. He agreed with Mr. Meyer that "we are all in the stretch business to some extent." He felt that stretching was almost invariably necessary to achieve full strength even when designed for 100 per cent loads initially. He agreed with Mr. Hitchcock that the stretch method becomes increasingly painful with airplane size and, in general, was opposed to a deliberate stretch policy for large aircraft and somewhat cool to the policy on smaller aircraft. He favored acceptance of structures tested to 95 per cent ultimate, as Mr. Hitchcock had suggested. He concurred that a critical review of the 1.50 safety factor was certainly in order and favored the category idea, but he felt that the factor should not be reduced in the case of structures not static tested.

Prepared comments were also available from Prof. F. R. Shanley of the University of California at Los Angeles and consultant for the RAND Corporation. In Mr. Shanley's absence, his comments were read by the chairman. Mr. Shanley pointed out that, from his own experience, he knew the 1.50 factor of safety was not based on any profound thinking or exact assessment of the variables it is supposed to cover. He concurred that a reduction in the safety factor appeared in order but in no case without adequate fatigue requirements. On the matter of the stretch design philosophy, he felt this depended heavily on the size of the airplane and the production schedules to be met but personally favored the "100 per cent design" method as outlined by Mr. Hitchcock. He suspected that much of the apparent advantage of the stretch method could be achieved analytically by better defined "rules of the game" and more accurate weight-prediction methods, the latter because the work at RAND has shown the relatively small fraction of the structural weight affected by design gross weight and other design parameters.

Considerable comment ensued from individuals in the audience, which demonstrated a keen interest in the subjects discussed by the speakers. Doubtless, controversy on these subjects was not resolved, but it was certainly clarified. Complete agreement was evident that provocative thoughts were aired and that progress was assured as long as such free expression of stimulating argument existed.

Transonic Testing Techniques

Dr. Hugh L. Dryden, Chairman
Director, National Advisory Committee for Aeronautics

Harold Luskin, Coordinator
Assistant Chief of Aerodynamics, Douglas Aircraft Company, Inc., Santa Monica Division

This session heard six papers dealing with the development of wind tunnels capable of operation continuously through the speed of sound. The first paper, "Transonic Wind-Tunnel Development and Operation at the Langley Aeronautical Laboratory of the National Advisory Committee for Aeronautics" by John Stack and Axel T. Mattson of the NACA Langley Laboratory, described the intensive theoretical and experimental work on test sections with slotted walls which led to the first large transonic tunnels to be placed in operation in 1950. A smaller transonic tunnel was operated in 1948. A general discussion was given of power requirements, wall interference, and shock-wave reflection. In the Langley development, the slots served both to generate supersonic flow and to reduce wall interference.

The second paper, "Transonic Wind-Tunnel Development at the NACA Ames Aeronautical Laboratory" by H. Julian Allen and Joseph M. Spiegel of the NACA Ames Laboratory, described a type of transonic tunnel in which the supersonic flow was generated by an adjustable nozzle upstream from the test section, so that the partially open test section walls served only to prevent choking and reduce wave interference. Experiments on slotted and perforated walls in a 5- by 5-in. tunnel were described. Data were given on the effect of varying porosity of the walls on shock-wave reflections.

The experience of the Cornell Aeronautical Laboratory was reported in a third paper, "Development and Operation of the C.A.L. Perforated Throat Transonic Wind Tunnel," by A. H. Flax, I. G. Ross, R. S. Kelso, and J. G. Wilder. Effort was concentrated on perforated walls and the shock-wave reflection problem. The complicating effects of the boundary layer on the shock-wave reflection were studied, as well as the use

of auxiliary suction with return of the air downstream of the diffuser.

The work carried out by USAF centers was described by Bernhard H. Goethert of ARO, Inc., in the fourth paper, "Flow Establishment and Wall Interference in Transonic Wind Tunnels." An interesting feature of this paper was the theoretical treatment of the influence of the boundary layer on wave cancellation and of the removal of boundary-layer air by auxiliary suction combined with wall divergence. Experimental data from the Transonic Model Tunnel at Tullahoma were included. The author concluded that perforated wall sections with auxiliary suction are superior to slotted sections with regard to wave cancellation.

The fifth paper, "Analysis of Several Types of Transonic Wind Tunnels," by Harlan D. Taylor, analyzed slotted wall, perforated wall, and profile streamtube transonic throat configurations on the basis of small-scale tests at the Research Department of United Aircraft Corporation. Certain properties such as flow generation, subsonic and supersonic tunnel-wall interference, and power requirements were compared. The profile streamtube technique surrounds a high-speed transonic core by a low-speed annulus in a solid test section. An application of this method was also described by Mr. Goethert in the previous paper.

The final paper, "Development of the Boeing Transonic Wind Tunnel," by W. S. Huntington and R. G. Peters, described the development of a transonic wind-tunnel configuration suitable for modification from an existing subsonic tunnel. The section was a slotted one with air re-entering the diffuser, patterned after the original NACA Langley development. The detailed design was based on experiments in a 1/20-scale model wind tunnel.

Field Trip

Thursday morning before 6:00 a.m., about 250 rugged individualists gathered at the IAS Building for the field trip to Edwards Air Force Base. The field trip included demonstrations of a high-speed sled, a motion picture of base activities, a welcoming by Richard Horner, Civilian Director of the base, and a flight line inspection of various operational and research aircraft. Lunch was served at the Officer's Club, and the afternoon was devoted to an inspection of the Rocket Test Facilities located 15 miles from the main base, across Rogers Dry Lake. During this phase of the inspection, a briefing of the Rocket Test Facilities operation was given by the test station personnel. Interesting color pictures of several different rocket motor tests were shown, including shots of a few "hard starts." The term "hard starts" is a gross understatement as applied to a rocket motor explosion and the ensuing fire. The bus trip back across the dry lake and return to Los Angeles concluded an interesting and memorable field trip.

Confidential Design Session

F. A. Cleveland, Chairman
Manager, Bomber Department, Lockheed Aircraft Corporation

R. G. Fuller, Coordinator
Lockheed Aircraft Corporation

The Confidential Design Session on Thursday evening concluded the 1954 Summer Meeting. Eugene L. Root, Director, Development Planning Department, Lockheed Aircraft Corporation, acted in the capacity of chairman in place of F. A. Cleveland, who had been called away on business during the week of the meeting. Mr. Root outlined the background of the development and testing of the Douglas X-3 supersonic research airplane.

The classification of the data presented at this session allows only the briefest outline of the discussion. The speakers presenting this study were Frank N. Fleming, Project Engineer; Harold Luskin, Assistant Chief of Aerodynamics; Harold Kleckner, Aerodynamics Engineer; Harold W. Adams, Chief Design Engineer; George C. Mabry, Flight-Test Engineer; and William B. Bridgeman, Engineering Test Pilot, all of the Douglas Aircraft Company's Santa Monica Plant.

Mr. Fleming presented the background of the X-3 development and a historical sketch of the basic problems and objects of design. He then described the airplane configuration and summarized the performance. Mr. Luskin described some of the aerodynamic research problems that developed during the conceptual phase of the program. Mr. Kleckner's talk dealt with the specific aerodynamic features of the airplane. Mr. Adams described some of the nuts-and-bolts problems encountered in the detail design phase.

The flight-testing program was presented by Mr. Mabry. This program was conducted in two phases. During the first phase Douglas evaluated the operational aspects of the airplane and then delivered it to the Air Force for the research flight-testing phase

(*Continued on page 64*)

Test Development of Structures Designed Understrength

JOHN H. MEYER*

McDonnell Aircraft Corporation

SUMMARY

Stretch testing, in which structures are designed understrength and brought up to strength by successive static tests, is discussed. The benefits of weight-saving in general are brought out and an approximate criterion for the value of weight presented. Data are presented on the scatter and stretch observed during various test programs. The sources of inaccuracy of analytical strength determinations are enumerated. Examples of stretch programs are described and the benefits discussed. A design process for exploiting stretch testing is described, and several factors entering into the choice of stretch-test methods are discussed. It is concluded that stretch testing is an extremely valuable tool in developing efficient aircraft structures.

INTRODUCTION

> Experimental Science does not receive Truth from Superior Sciences: she is the Mistress and the other Sciences are her Servants.
>
> ROGER BACON: *Opus Tertium*

STRETCHING STRENGTH by testing is done by designing structures deliberately understrength and developing them by a series of tests. Successive "soft spots" are located and reinforced until the desired strength is reached. This process is called "stretch testing."

In developing the ability of a particular model of airplane to operate at higher gross weights, factors other than stretch testing may be used. Conservatism in the design criteria or conservative load analysis may open up ways to clear the airplane for higher gross weights, when additional insight becomes available as a result of wind-tunnel measurements, flight loads testing, or service operations. However, the present paper discusses only the benefits obtainable from strength-testing procedures.

NOT A NEW IDEA

There is nothing new about this procedure. It is the rule rather than the exception in many industries. Engineers in some lines of business are able to subject their structures to service conditions so conveniently that it is cheaper and better to cut and try than go through an exhaustive analytical determination of loads, stresses, and allowables before service testing. Structural development programs of this nature are described by Jung,[1] dealing with trailers, and Drew,[2] dealing with turbine stresses. This method has been suggested for use in aircraft structures on many occasions, for instance, by Walker[3] and Driggs.[4]

LIGHTNESS IS IMPORTANT

First we must decide what amounts, of time, manhours, and money it is wise to invest in making certain weight-savings.

There has never been a good system invented to demonstrate vividly the importance of pounds to airplanes. One usually attempts to appraise their value by computing performance changes. Such a set of figures is given in Table 1 for the F2H-1 Banshee.

These dreary numbers somehow fail to convey a vital sense of the real value of saving a few pounds. If one understands the fighter pilot's feelings when a MIG stalls out of a turn behind him or, when highly overloaded, he brushes the treetops after a 10,000-ft. take-off run, one comes closer to an understanding of the importance of small performance gains.

As Stephen Potter says in his book *Lifemanship*, "If you're not one up, you're one down." Wars are won because, in a series of individual encounters between men and situations, one group of men comes out one up more frequently than the other group. And any combat pilot can tell you that a very slight difference in performance of an airplane can make the difference between "one up" (successful mission) and "one down" (pushing up daisies).

Heinemann has presented[5] a striking way of illustrating the importance of weight-saving by pointing out the sizable secondary weight penalties involved when one adds dead weight but, at the same time, changes every part of the airplane by a small amount to get back precisely the small performance losses brought on by the dead weight. Unfortunately, there are many who do not really understand what Heinemann is getting at, or do not believe his results, or both.

The dollar value of weight to a commercial airplane is a problem in economics, and several papers have been written reaching conclusions on this subject. In military aircraft, the problem is not solely one of economics, but some light can be shed on the value of a pound of weight by considering the amount of weight which will render the airplane useless for its tactical mission and using this as a yardstick against the economic factors involved in: the investment of the military establishment for operation of the airplane, the value of national wealth protected by the airplane, the capacity for destruction of enemy wealth, the economic effect on the airplane manufacturer, and pilot safety.

Presented at the Structures Session, National Summer Meeting, IAS, Los Angeles, June 21–24, 1954.

* Chief of Structures, Airplane Engineering Division.

How to put all these things together—assuming data were to be assembled in the first place—is, among other things, a rather profound philosophical problem.

A Weight Value Criterion for Use in Design

Without belaboring this issue any further, suffice it to say that at McDonnell we have come to the conclusion that weight-saving is important to fighter airplanes and have established a criterion for its importance as follows:

(a) In engineering, we can spend up to 50 man-hours design time to save a pound on a given design, other things being equal.

(b) In manufacturing, we can spend up to 10 man-hours per lb. for each airplane, other things being equal.

Further qualifications are involved, particularly in regard to facilities and timing, but this represents the basic idea.

While it is always precarious to say anything about weight in terms of dollars, it is noted that this criterion approves the expenditures of about $25,000 on *engineering* 100 lbs. out of a design and over 2 million dollars in *manufacturing* 100 lbs. out of each plane of a 500-airplane contract. It is not asserted that this is necessarily a realistic evaluation, for the criterion breaks down in either limiting case, and perhaps this instance is beyond its realm of validity.

To sum up, the small performance increases associated with small weight changes are extremely important and justify considerable effort in their attainment.

Potential Weight-Savings

Let us turn our attention to assessing the potential weight-savings in going through a stretch-testing program. As a first approximation it might be asserted that there are none at all. The course of reasoning might run as follows:

(a) A required strength level is clearly defined by specification.

(b) Stress analysis will define for us member sizes that will just attain, but not exceed, the required strength level.

Table 1

F2H-1 Performance Improvement by Weight Reduction
(Using 430 lbs. or 10 per cent of the designed material in the manner noted.)

Performance Item Affected	Performance Increase	Nature of Design Change
Rate of climb	7,500–7,750 ft. per min.	Omitting weight
Range	1,388–1,495 miles, at 30,000 ft.	Adding 72 gal. of fuel
Combat radius	344–402 miles	Adding 72 gal. of fuel
Minimum radius of turn at 40,000 ft.	1,490–780 ft.	Decreasing wing loading to the extent of a 430-lb. heavier wing
Take-off run	1,240–1,140 ft.	Leaving out weight
Take-off run	1,240–1,100 ft.	Installing engines of 12.5 per cent more thrust
Stalling speed	102–76 knots	Decreasing wing loading to the extent of a 430-lb. heavier wing

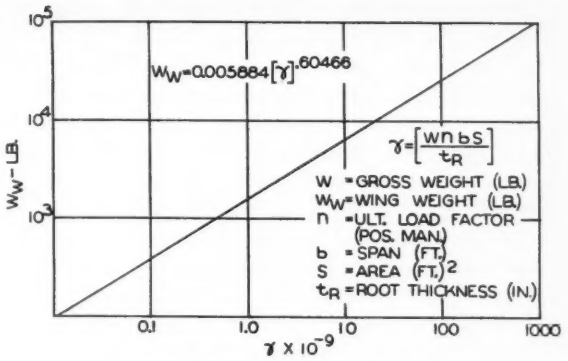


Fig. 1. Wing weight estimation chart.

(c) Stress analysis is an exact science.

(d) Therefore, any gains made in subsequent stretch testing are illusory—that is, they appear because material properties are not minimum; the test setup is less demanding on the structure than the flight condition it attempts to simulate; various design factors needed for something other than static strength appear as excess static strength, etc.

Test Results Scatter

A review of results achieved in various static test programs soon dispels confidence in the above approximation. Walker has evaluated[3] a broad static test experience and has found some very interesting results. In a group of 24 wings, initial testing showed that the strengths ranged from 55 to 145 per cent of the designer's objective, with a mode of about 90 per cent. After one or two (usually one) modifications, the strengths ranged from 75 to 145 per cent of the designer's objective, with a mode of about 110 per cent.

The writer has not been able to find published records of stretch-test results other than those of Walker[3] and Schwartz.[6] There are several papers demonstrating that static test results scatter a great deal from the desired strength level. Gordon and Holback state[6] that 25 to 30 per cent of Martin tests to ultimate load suffered premature failures. Colonel Schwartz has summarized[6] premature failures on A.A.F. aircraft up to 1946. Some of the data:

(a) During 89 wing test programs, 50 failed below design ultimate, ranging from 40 per cent ultimate upward. Data are not given for failures above ultimate. Five required more than three retests to bring them up to strength.

(b) Of 87 fuselages, 46 failed below design ultimate.

(c) Of 83 horizontal tails, 17 failed below ultimate.

(d) Of 72 landing gears, 27 failed below ultimate.

Unfortunately, Colonel Schwartz's data did not cover failures beyond ultimate. However, the data lead one to believe that some rather sizable strength deficiencies were brought up to design ultimate by stretch testing.

From a knowledge of these and other test results, it is apparent that the question of stretch testing has already been settled. We are all using it. So, the real

question is not shall we or shall we not, but to what extent and with what degree of conciousness.

In the "general case," we may conclude that a sizable strength increase can be obtained from local beef-ups on structures designed without any great emphasis on their adaptability to stretch testing. The results offer reason to believe that deliberate exploitation in design, plus willingness to go through a few modifications on each major component in the stretch process, may allow a sizable overstrength to be achieved. Or, conversely, a sizable weight-saving may be achieved by capitalizing on the stretchability of structures.

The writer considers that 15 per cent stretch via testing is perfectly feasible on any normally complicated aircraft structure, and 25 per cent is attainable with moderate pain and strain.

The Improvement in a Specific Case

Using a specific airplane of 35,000 lbs. combat weight, a 900-lb. weight-saving can be obtained in a 15 per cent stretch. Fig. 1 is a plot of estimated wing weight for fighter aircraft derived by Kelley[7]; from this plot it is found that the wing weight difference between a 7.5g wing and a 6.4g wing is 300 lbs. Extending this percentage weight-saving to the other basic structural components of the airplane here considered results in another 350 lbs. A secondary weight-saving of 350 lbs. is taken from fuel and fuel system to hold constant range (more weight could be taken out of the airplane without reducing performance below the original level), and 100 lbs. is allowed for beef-up during stretch testing, for a net weight-saving of 900 lbs. The airplane performance has been increased by this maneuver, since all performance but range has benefited by the weight decrease.

Analytical Strength Determinations Are Not Precise

Having observed that structural designers are not successful in building the strength level desired into a structure, let us survey the factors that cause the situation.

The necessity for overriding considerations beyond the stress analysis was first called to my attention in 1940 at Consolidated. Roy Miller, the Chief of Structures, was looking over several large assembly drawings and listening to the story on stresses and allowables. The more he looked, the unhappier he got, and he concluded his review with a statement to this effect: "The more engineers we hire, the longer they spend analyzing these structures, and the heavier the structures get. Cut all those 0.064 gages to 0.051."

As noted in Table 2, initial XF2H-1 wing tests resulted in an extensive failure at 100 per cent of limit

Table 2*

Major Component Test Results and Stretch Obtained

Test Article	Initial Failure, Per Cent Limit Load	Modification	Next Test Result, Per Cent	Modification	Next Test Result, Per Cent	Stretch, Per Cent	Estimated Weight Penalty, Lbs., Per Airplane
XF2H wing	100	Redesign torque transmission system at wing-fold	Failure at 100, 105, and 115	Strengthened breakable tip and minor beef-up	140	40	Less than 5
XF2H fuselage, critical flight condition	60	Reinforce locally	Failure at 145	.....	.....	142	5–10
XF2H stabilizer (modification 2)	110	Reinforce fitting	Failure at 126	.....	.....	15	
F2H-2 wing	146	Reinforce spar cap over 20 in. length	Failure at 170	None	None	18	10 ±
F2H-2 fuselage	145	Increase catapult fitting local attachments and fuselage backup structure	Failure at 163.5	Change fitting	No failure at 165	14	About 5 or 10
F2H-2½ and F2H-2¾ wing	170 (F2H-2 failure)	Add straps to spar caps, strengthen several attachments	185 flange buckle	Reinforce landing gear beam	185 general failure, started in nose torque box‡	27	25 ±
XF3H-1 wing	127	Redesign wing-fuselage match angle locally	Failure at 135	Reinforce rib	170 (slat failed, wing did not)	34	Less than 5
XF3H-1 stabilizer	168 (Elevator failed, stabilizer did not)	None	Failure at 155†	None	None	None	None
XF3H-1 fin	155	Reinforce root rib	187	.....	.....	21	2
XF3H fuselage, flight loads	150	None				None	None
XF3H fuselage, catapult loads	139	Reinforce fuselage at catapult hook	None	.....	.....	Unknown	5–10
XF3H fuselage, arresting loads	95	Increase rivet strength through fuselage skin	Failure at 143	Local fuselage strength increase	150, no failure	58	Less than 5

* Failures are corrected to minimum properties in some cases.
† Ascribed to revised method of applying loads.
‡ 185 per cent F2H-2 load = 149 per cent F2H-3 load for this failure.

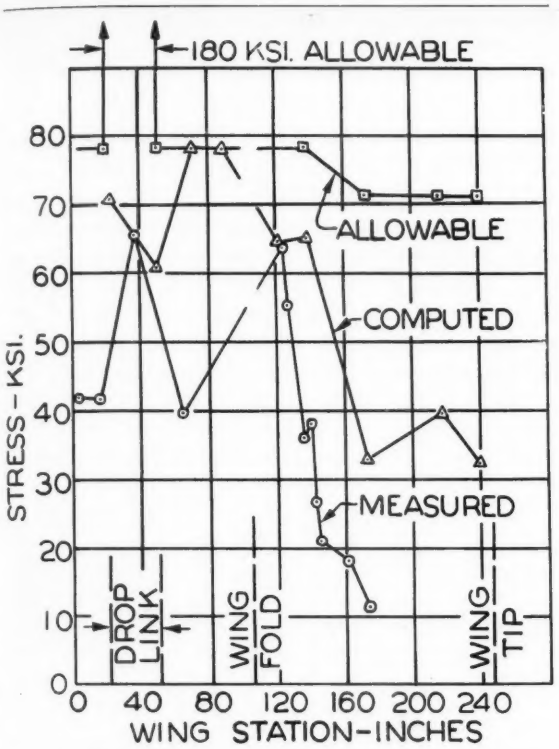


FIG. 2. F2H-2 computed and measured rear spar lower cap stresses for LAA (critical) condition, 150 per cent limit load.

load. A torque fitting at the wing fold, which was supposed to supplement the ability of the main fold fittings to transfer wing torsion from the outer to the inner panel, had slipped out of its receptacle. While no individual stepped forward to claim responsibility for this deficiency, it was agreed that any one of several indivduals should have predicted this failure by spending a few minutes cogitating on the combined mechanical and structural considerations involved.

This case illustrates what is going on, to a greater or lesser degree, in all analytical determinations. When we face the fact that this sort of thing is inescapable we must then grant the positive value of stretch testing. So let us take a closer look at the influences that cause designers to produce nonoptimum structures.

(*a*) *Complexity of Arrangement of Members*—A look at any swept fighter wing structure tells the story. The so-called "primary structure" may present fairly straightforward load paths. The so-called "secondary structure," while attached firmly to the primary structure, is interrupted by wheel wells, control surfaces, wing fold points, cutouts, and doors and often includes sizable members that weigh a good deal but are not so disposed as to make it clear to the designer that they can be of any assistance to the primary structure in carrying its loads. Weight analysis of airplane structures makes it clear that they contain a good deal more material than is necessary to carry just the loads. Lutz analyzed[8] 16 transports, bombers, and fighters and found that the fighter wings contained 3.3 to 3.7 times as much material as was necessary to carry the load when designed in an optimum manner. Our experiences with the behavior of structures under load make it clear that part of this "nonstructural" material actually does carry appreciable load, in spite of the fact that our calculations using standard assumptions and methods do not allow for it.

(*b*) *Inapplicability of Standard Stress Analysis Methods*—Vast masses of material are available on methods of analyzing various structures. Applying any of these methods involves "idealizing" the structure to conform to the structure for which an exact method of analysis is available. "Idealizing" a structure usually means divesting it of all secondary material. The secondary material is the source of some extra strength. This difficulty is not entirely avoided by increasing the complexity and redundancy of the idealized structure. The best that can be done, and still keep stress analysis down to a reasonable volume, leaves many unevaluable overstrengths in a structure.

(*c*) *Nonlinearity of Structural Components*—This refers to the type of structural behavior in which stress is not proportional to strain or, what is the same thing, it means that the load vs. deformation characteristic has a curve in it. Most of our stress analysis formulas assume Hooke's law in their development, and we take care of the recognized nonlinearities, or plasticity, of the basic materials of construction by various factors worked up for various cases. However, the internal load distributions depart from our classical analytical predictions because of many effects other than basic material properties. Some of these effects are peculiar load-strain characteristics in joints of all types; sheet metal buckling, which sets in at different load levels in different panels; and, tension beam-column and compression beam-column effects, which show up in local parts of a complex structure as well as in the larger components.

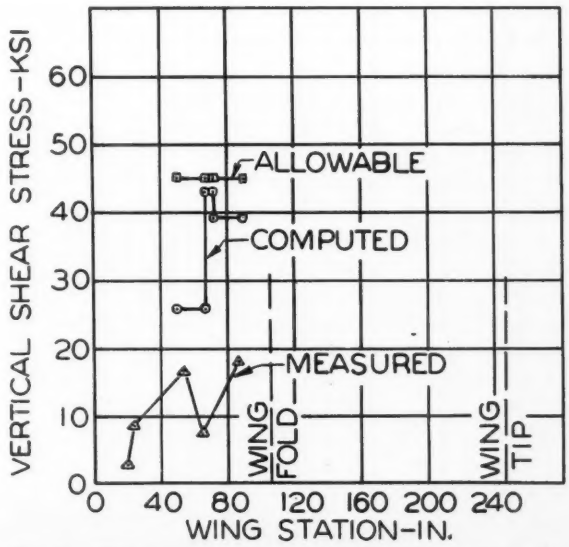


FIG. 3. F2H-2 computed and measured front spar web shear stresses at LAA condition, 150 per cent limit load.

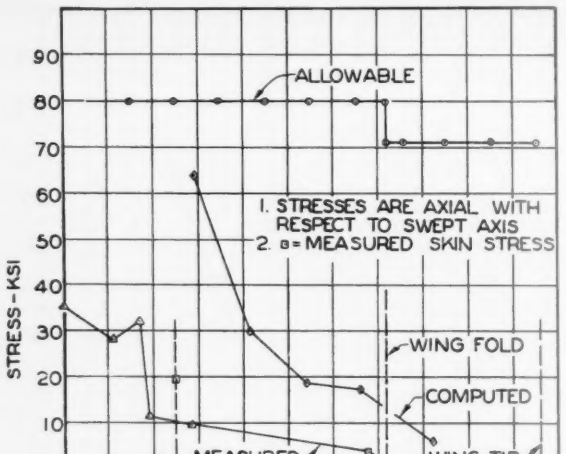


FIG. 4. XF3H-1 main beam lower cap stresses at 150 per cent HAA (critical) limit load.

The net result of the nonlinearities is that stress patterns depart widely from those computed by the stress analyst. Including many redundant assumptions in the analysis does not improve this situation appreciably.

LABORATORY VS. ANALYTICAL STRESSES

Comparisons of measured and computed stresses are given in Figs. 2 through 4. These are particular cases that were readily available and are not selected as extreme situations. In interpreting the true significance of the differences between the computed and measured stresses, these factors should be kept in mind:

(a) The measured stresses are obtained from strain gages placed at sections where the highest stresses were expected. However, the strain gages measure gross stresses between attaching holes, while the computed stresses are net stresses at sections containing rivet or bolt holes. Net sections may contain as little as 80 per cent cross-sectional area of the adjacent gross section.

(b) Strain gages were carefully placed to avoid false readings due to secondary bending; usually more than one gage was so disposed with respect to the centroid of the member as to cancel out any unknown secondary bending stresses. Thus the strain reading is not an extreme fiber strain. The computed stress represents conditions at the extreme fiber. The discrepancy shows up in Fig. 4 as a 2 to 1 difference at station 50. This is probably a perturbation in local stresses, since the ratio of distances from neutral axis to the fibers in question is on the order of 1.5 to 1.0.

Taking these factors into account, it still must be conceded that the analytical determinations on the bulk of the structure predict considerably higher stresses than actually occur.

Fig. 4 shows that in the XF3H wing the computed stresses are also low with respect to allowable stresses. Lest the reader conclude this indicates a poor standard of structural efficiency, it is pointed out that considerable extra material was added to the wing plating beyond that required for strength in order to provide adequate rigidity for flutter. About 500 lbs. beyond the strength requirements went into this wing.

IS THE SITUATION INTOLERABLE?

Perhaps we should look on this state of affairs as a deplorable situation with which we should not consent to live. Perhaps, like St. George sallying forth after the dragon, we should dedicate our time and effort to removing the necessity for complex arrangements and to perfecting stress analysis procedures to the point where all the secondary strengthening effects become understood. This may be so, but the writer thinks not. When structures are uncomplicated to the extent that they look like test specimens, the airplanes will suffer sadly. And the perfectibility of stress analysis of complicated structures is in the same category as the perfectibility of man's basic nature. The progress we have made along that line in the 5,000 years of recorded history is well established by our present preoccupation with the design of implements of war.

PERSONNEL FACTORS

To this point, the term "structural designers" has been used as though they were an "off the shelf" unit, all alike. To inject a nontechnical note, structural designers are all different. In the foregoing discussion, there has perhaps been the implication that the state of the art exemplified by the latest structural theories was being practiced by structural designers. Actually, airplane structures today are almost universally being designed by groups of engineers, one-third of whom have less than a year's experience. These less experienced men, who do most of the specific defining of member sizes, have barely heard of most of the refined techniques available in the more secluded fields of structures and have not stood in a test laboratory and watched their theory of the mode of failure fail as the test specimen fails. Speaking as a working stress analyst, the writer suggests that one of the marks of the less experienced analyst is a tendency to be quite sure his particular structure is strong. One learns early in the game that there are extremely objective criteria for deciding whether a particular part is understrength but no criteria in the world to determine whether a particular part is overweight. It is a tribute to the supervisors of this band of young Turks that the structures are as good as they are.

We may hope this situation is temporary. However, an appraisal of future prospects for engineering graduates, in the light of current and near future engineering needs and in view of a prospect of continued international tension, makes it fairly evident that the situation will continue for several years.

While this situation may not concern the theoretician, it is of vital concern to all who must actually produce high-performance aircraft and must be fully

taken into account in the overall decision of how to accomplish a structural design.

We conclude that the sources of error in analytical predictions of strength arise because standard methods are an inadequate basis for designing complex structures, the best available current methods do not actually get used, and human fallibility gets into the picture.

Some Stretch-Test Results

McDonnell Aircraft used a "design for stretch testing" philosophy in the case of the XF2H airplane (10 per cent under). The process was also invoked in the F2H-3 development and is currently being used on an Air Force fighter. Fig. 5 is a general view of the F2H-2.5 test setup and is typical of all the F2H series tests. A résumé of these and other results is of interest.

Table 2 is a listing of the stretch obtained in several programs. These cover a random group of major components for which results were readily available. There has been no selectivity on the basis of the results.

The XF2H designers aimed at −10 per cent margins. How much weight was saved by this procedure has not been evaluated, nor could any realistic evaluation be made, since there were sizable load changes during the course of the design, principally affecting the chordwise location of the extreme centers of pressure on the wing and, correspondingly, the tail loads.

Getting the XF2H wing up to 140 per cent (ultimate for that particular airplane) was a difficult process, as shown in Table 2, and we had no inclination to try to stretch beyond ultimate.

The writer was Project Stress Engineer on the XF2H. The difficulties during testing were greater than usual primarily because the design was spottier than usual. At one time the wing stress group consisted of three Chinese Nationalist Army officers on loan to learn about airplanes and, as group leader, a civil engineer a few years out of college. The officers were quite skilled in engineering fundamentals and worked very hard, but there was a period during which neither the Kunming boys nor the corn-belt boys were entirely sure of what the other group was up to.

Fig. 6 shows the final failure of the XF2H, after several previous minor failures had been beefed up.

What weight was saved on this XF2H stretch remains unevaluated.

F2H-2 Wing Testing

Following through the F2H wing results, Fig. 7 shows the initial 146 per cent failure of the F2H-2. The spar cap was reinforced locally by addition of a steel strap and heavying an adjacent door. After this reinforcement, the wing failed at 170 per cent at the wing-fuselage intersection, as shown in Fig. 8. A general view of the wing at 155 per cent is shown in Fig. 9.

A subsequent program was aimed at stretching the F2H-2 structure to F2H-3 loads. The first phase was

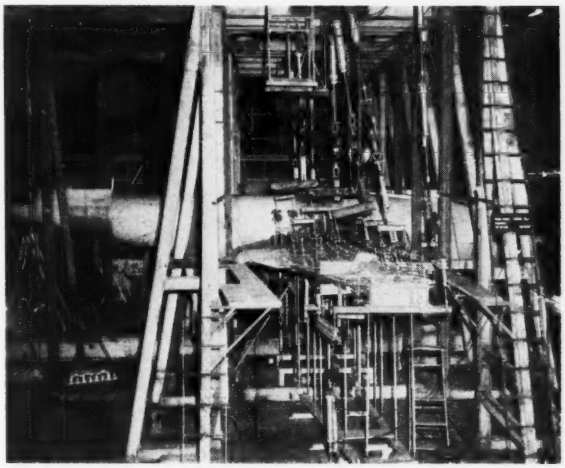


Fig. 5. General view of F2H test setup.

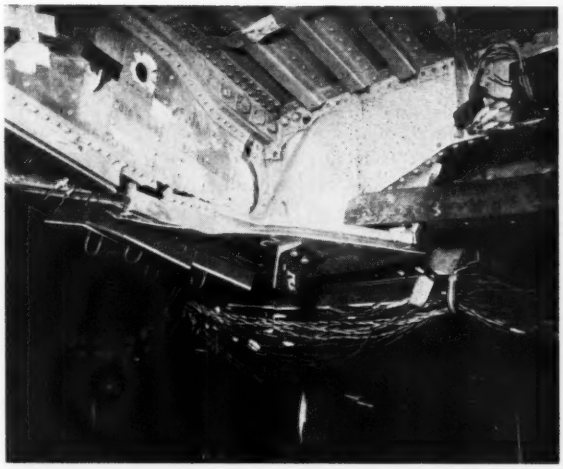


Fig. 6. XF2H-1 wing failure, 140 per cent limit LAA condition.

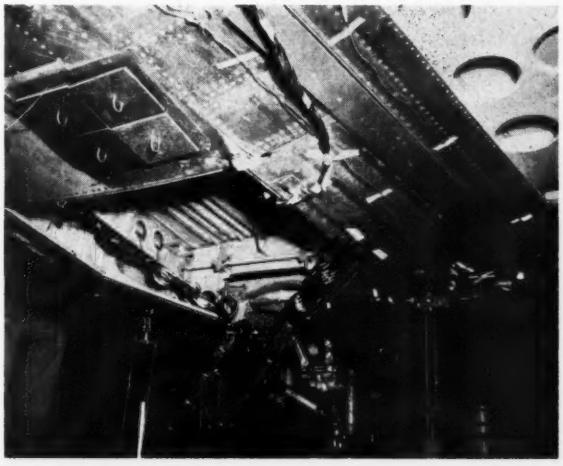


Fig. 7. F2H-2 wing failure at 146 per cent HAA limit load.

designated the F2H-2.5 program. For those tests, the weak points indicated by F2H-2 tests were reinforced. A typical reinforcement is shown in Fig. 10. The external plate beefs up the spar cap just inboard of the steel strap mentioned above. Straps were also added at the failing point in Fig. 8 and elsewhere.

Tests Between the F2H-2 and F2H-3

The F2H-2.5 failed at 185 per cent, just outboard of the engine. Further reinforcements were added for the F2H-2.75 tests, which used F2H-3 loads as a basis. As shown in Fig. 11, failure occurred at 149 per cent of these -3 loads, an extensive failure in the engine region. The 149 and 185 per cent load levels are practically identical in bending moment. The structure thus appears to have been stretched to the limit.

To make this story complete, it must be noted that the structure developed in this stretch program was not carried over identically into the F2H-3 airplane. Due to a snowballing effect of added equipment, accompanied by performance losses, the F2H-3 design loads settled down to a few per cent over the strength level attained during the F2H-2.75 stretch-test program. A fair amount of airplane structure was redesigned, but the benefits of the stretch program were conserved by proportioning strength on the basis of the stretched structure rather than the stress analysis.

F2H-3 Testing

After a few preliminary difficulties, the -3 wing failed at 174 per cent as shown in Fig. 12. There is a startling similarity between the final F2H-3 failure and the XF2H-1 failure 5 years earlier. The wing bending moment for the -3 failure was 167 per cent of that for the XF2H at the failing wing station.

A subsequent evaluation of the F2H-3 wing, using weight estimation, led to the conclusion that we had actually saved 86 lbs. on the wing as a result of the F2H-2.5 and -2.75 tests. The weight of the bare wing structure was about 1,400 lbs. The 86 lbs. is the estimated difference in wing weights between the F2H-3 as built and a hypothetical F2H-3 wing as designed without benefit of stretch testing.

From rather unspecific records available, it was estimated that the F2H-2.5 and -2.75 test program cost about 6,000 man-hours; thus about 70 man-hours were spent per pound of weight saved.

Going back to Table 2, it is seen that there is a fairly sizable strength increase obtained in most of the individual stretches. This is not surprising in the range below ultimate load; however, it showed up forcefully in the F2H-2.5 and -2.75 program, where the structure was wrung out to 185 per cent of limit for a total stretch of 123 per cent of the original design objective for the structure. In this particular case, the original F2H-1 structure had been designed for zero margin throughout, with no provision anywhere for subsequent stretch.

More Examples of Good Stretch Results

Another item worthy of note is the XF3H fin. The initial failure was 155 per cent. Subsequent loads work made it appear worth while to stretch the strength if possible. So the root rib was reinforced, and during retest the fin failed at 187 per cent.

Another good example of a sizable stretch is the F2H series main landing gear. The main legs of the F2H-2 weighed 655 lbs. per airplane and were originally designed for an airplane landing weight of 14,400 lbs. and a limit load factor of 4.6. The critical design ultimate loading consisted of 15,800 lbs. drag and 46,500 lbs. axial compression. The F2H-3 uses essentially the same strut (the weight is 705 lbs. per airplane) for an airplane weight of 16,700 lbs. The F2H-3 critical ultimate loads occurring during laboratory drop testing were 31,000 lbs. drag and 80,000 lbs. vertical load. The total stretch above the original designer's objective was about 80 per cent.

Design Procedure for Exploiting Stretch Testing

The usual policy involves asking the structural designers to design everything to zero margin, with the time-honored factors for fittings, ignorance, etc. The criterion of excellence is the static test; if all components are on the verge of failure at ultimate load and fail just enough above ultimate to correct back to ultimate, the design is perfect. As we have seen in the previous discussion, this does not happen.

Here is a set of ground rules aimed at exploiting the structure via stretch testing:

(*a*) *General Policy*—The analytical design target is to provide 85 per cent of the specified strength. The understrength regions are to be brought to full strength during the stretch-test program.

(*b*) *Weights*—Estimated weights are based on the reduced strength level, and bogey weights are set up accordingly. In setting design gross weights, no reduction is made on the fuel, equipment, store, etc., loadings—i.e., the loading configurations are taken as those fully consistent with the intended airplane usage. It is advisable to keep a record of the weight estimated for a full-strength airplane and the estimated savings via stretch on each component. Vigorous weight control measures during the design phase are essential, as always.

(*c*) *Performance*—Based on the above weight estimate, thus capitalizing on the structural efficiency accruing from the stretch.

(*d*) *Loads*—Computed for the full-strength airplane, using weights as estimated above.

(*e*) *Structural Design Policy*—

(1) The general strength level is to be margin of safety = −15 per cent.

(2) All the usual fitting and other factors are applied over and above the basic −15 per cent strength level.

(3) Single members at points in a statically determinate structure—i.e., statically determinate with re-

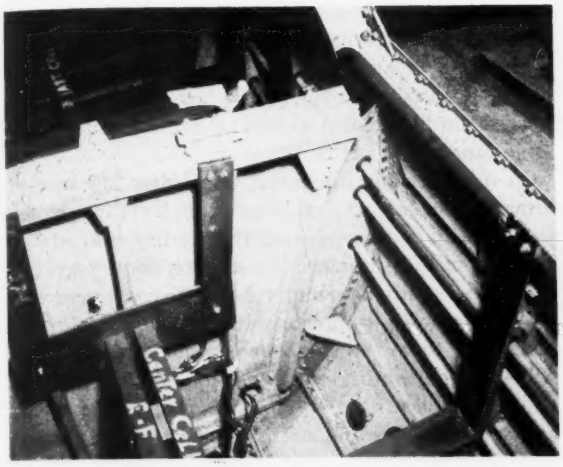


FIG. 8. F2H-2 wing failure at 185 per cent limit load.

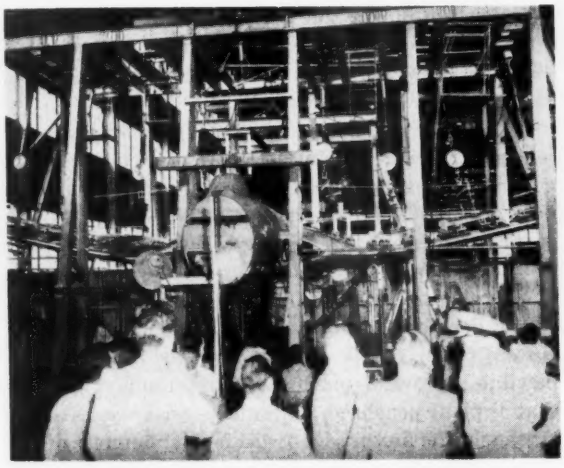


FIG. 9. F2H-2 wing at 155 per cent LAA limit load.

FIG. 10. F2H-2.5 wing spar beef-up.

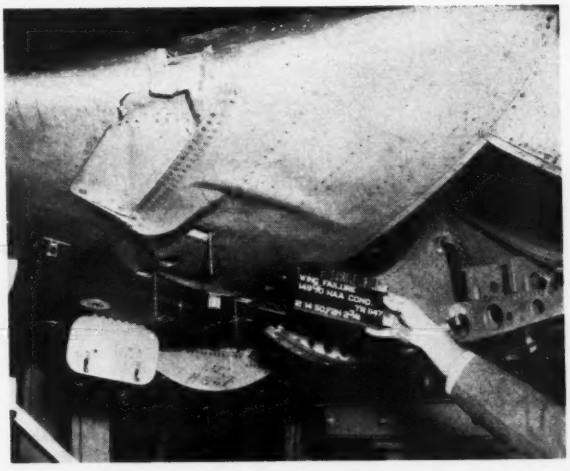


FIG. 11a. F2H-2.75 wing failure at 149 per cent of F2H-3 HAA condition.

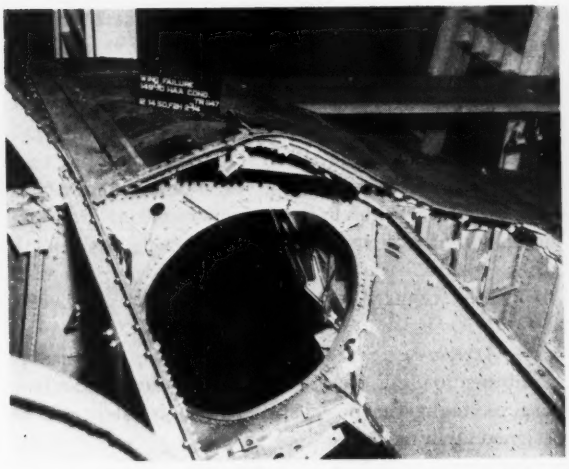


FIG. 11b. F2H-2.75 wing failure at 149 per cent of F2H-3 HAA condition.

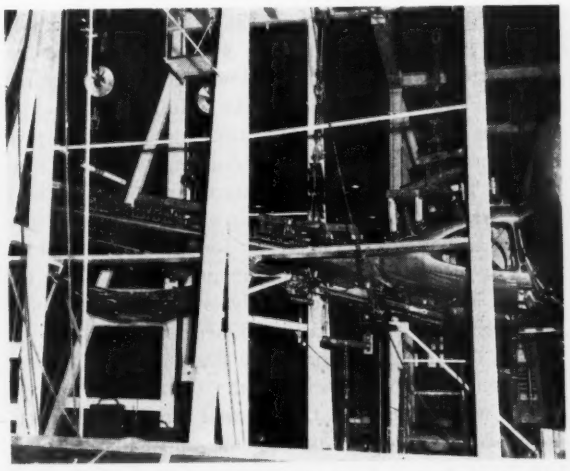


FIG. 11c. F2H-2.75 wing failure at 149 per cent of F2H-3 HAA condition.

FIG. 12a. F2H-3 wing failure at 174 per cent limit LAA condition.

spect to internal distribution of forces as well as boundary loads—are to maintain zero margins. This may be the case at wing-fold attachments, landing-gear trunnions, and similar points, but it must be clearly understood by all analysts that it is not the case in components made of more than a few individual pieces of material.

(4) Further qualifications may be necessary depending on the timing of the design stage, the static program, and the production run. The static tests must be completed ahead of the first airplane requiring full load factor, otherwise expensive backfitting of repairs is necessary.

(5) No stigma attaches to failure at the 85 per cent strength level.

(*f*) *Aeroelasticity*—Stiffness calculations for use in modifying loading conditions, flutter, lateral control, etc., are to be the best estimate for the structure as designed analytically.

(*g*) *Static Tests*—Loading schedules are based on the above load reports—i.e., static test target is 15 per cent above the analytical target. Strain gages should be installed at strategic spots and monitored after each load increase. This reduces the probability of catastrophic failure below specified strength. A clear indication of incipient failure below specified strength is cause for shut down of testing and local reinforcement.

There are other ways of setting up a stretch procedure, such as using lowered weights, load factors, or loads. The above procedure seems most satisfactory to the writer because it can attain all the benefits of any system and avoids the necessity for the rewriting of reports or other horse-changing in midstream. The exception is the formal stress analysis report, which must be rewritten if it is considered necessary to have on hand a document purporting to show analytically that the strength is up to specification.

The writer considers that formal stress analysis reports are a complete waste of time and effort. Static and flight testing have actually supplanted the stress analysis as proof of structural integrity. The formal stress analysis is an outworn habit of the days when there was no better way of determining structural integrity. Abolition of formal stress analysis reports is long overdue and, when accomplished, will release many engineering man-hours for constructive work. All functions currently involving the use of stress analysis reports can be handled as well by other means and, in some cases, much better.

In the foregoing discussion, the writer has tried to bring out the factors that make stretch testing feasible and presented data showing that it has worked. In deciding how extensively to use it on some particular case, these additional factors should be considered:

(*a*) *Timing*—A complete static program of the type performed today takes about 12 months on a Navy fighter and 8 months on an Air Force fighter, testing on two shifts and using the third shift for overflow testing and setup. Using the stretch concept will involve an extra 2 or 3 months, depending on the extent. The test article must be made available early enough so the changes dictated by the stretch program can be put into the production run of airplanes. A program that involves slow production for a year or so, while the wrinkles are being worked out of the many other aircraft characteristics and systems, is readily adaptable to a stretch-test development program.

(*b*) *Growth Potential*—If the designer wants a fair amount of weight growth potential, stretch testing is a good way to get it. A 15 per cent strength increase over original design target is a readily attainable goal. If the designer wants the entire 15 per cent for purposes of loading down the airplane with more equipment, the basic strength level must be raised accordingly.

The decision to be made by the manufacturer and customer is: Should weight growth be considered inevitable, provision made for it, and the first model of that airplane penalized performance-wise because of it? Or should the first model be made minimum weight for maximum performance, knowing that weight growth in subsequent models, if imposed, will be much more painful—perhaps require basic redesign? This is a difficult question to answer. We have answered it

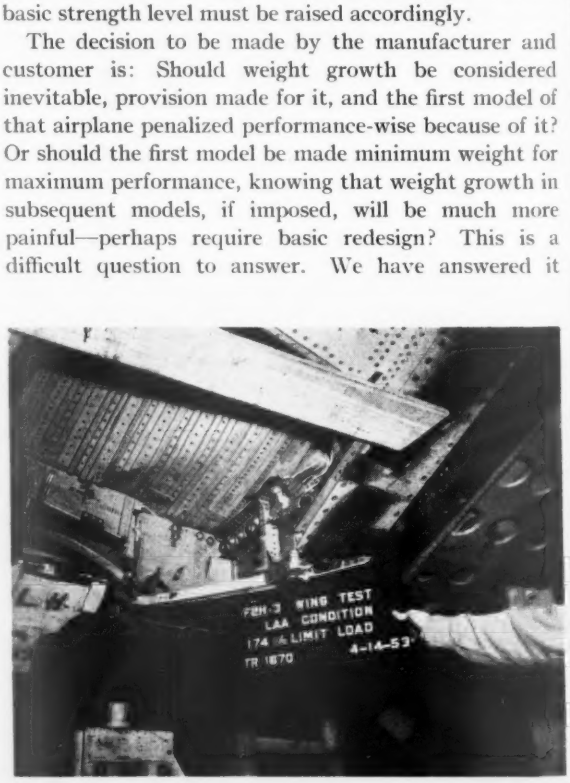


FIG. 12b. F2H-3 wing failure at 174 per cent limit LAA condition.

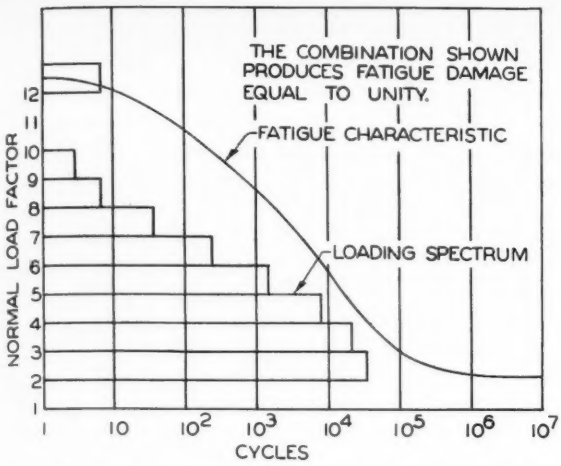


FIG. 13a. Load spectrum and S-n curve for hypothetical fighter wing.

most often by giving the customer the highest performance possible in the particular airplane he has ordered.

(*c*) *Fatigue Considerations*—This discussion has implied that an airplane that has adequate static strength will have adequate service strength. It is known that such is not the case. The fatigue problem has recently proved critical with respect to fighter aircraft, and some consideration needs to be given to the question of whether too much of the stretch-testing philosophy may not create an airplane with unsatisfactory fatigue characteristics.

Fatigue is a difficult problem to deal with. While we have certain fighter airplanes with fatigue troubles, we have not yet been able to set up a criterion of what constitutes satisfactory fatigue life.

Using the stretch philosophy, we shall build airplanes with higher operating stresses. The general effect of higher operating stresses is to reduce the resistance of the structure to repeated loads. It has been observed that fatigue difficulties are usually associated with a local design condition in which a substantial stress raiser is superimposed on a high nominal operating stress level. These conditions are generally localized in any structure, as indicated by Figs. 2 through 4.

Using somewhat oversimplified concepts, a fatigue analysis has been made for a hypothetical airplane wing. The essentials are charted in Fig. 13a. In this figure, a reasonable S-n curve considered applicable to the case $R = 0$ is presented, and a loading spectrum that causes the calculated fatigue damage $\Sigma(n/N)$ to equal 1.0 is shown. This loading spectrum is proportioned in such a way as to represent the actual distribution of peak loads at various load factors that fighter aircraft actually encounter. Of course any such data are open to question, since there is no great amount of statistical data of this sort to draw on.

The fatigue damage resulting from the S-n characteristic and loading spectrum of Fig. 13a is plotted as a function of load level in Fig. 13b. It is seen that the bulk of the fatigue damage is produced by load peaks in the vicinity of 4*g*.

Investigators of fatigue phenomena have concluded that the effect of stress concentrations are different at high and low load levels. Stress concentrations have a large effect at the high-cycle, low-stress end of the S-n curve and little effect at the high-stress, quarter-cycle end of the S-n curve. The effect in the intermediate ranges has been found[9] to vary in a fairly uniform manner from an allowable stress reduction—almost equal to the theoretical stress concentration factor at the endurance limit—to an allowable stress reduction—on the order of half that indicated by the theoretical stress concentration factor at lifetimes of 10^4 cycles. Considering that the 4*g* level is the major damage producer for fighter aircraft and that this 4*g* level is associated with a lifetime of 10^4 to 10^5 cycles, it seems reasonable to conclude that, at a localized potential fatigue nucleus, a 15 per cent increase in 1*g* stress level can be completely washed out fatigue-wise by a 30 per cent decrease in the local theoretical stress concentration factor. This is a difficult, but not unattainable, design goal.

It is believed that use of stretch-test design philosophy requires closer attention to detail design than has heretofore been the case. Such a course is also advisable in view of potential fatigue difficulties, whether stretch testing is invoked or not. Good detail design is a different thing from accurate stress analysis. The factors working against accurate stress analysis were discussed previously. Good detail design involves the careful arrangement of members so that load lines of intersecting members pass through a point; avoidance of abrupt changes in section; generous fillet radii and all other re-entrant radii; and avoidance of all geometrical arrangements of fittings and members leading to stress concentrations larger than three or thereabouts. This matter of careful proportioning of

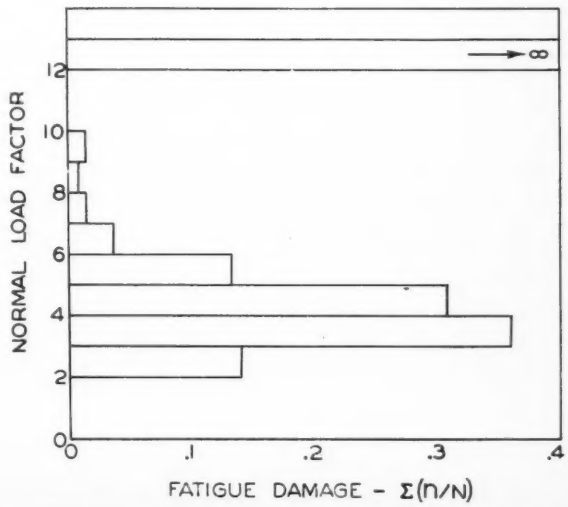


FIG. 13b. Fatigue damage as a function of load factor.

detail parts is an endeavor above and beyond the determination of the magnitudes of loads in various members, which is a major concern in stress analysis. It is believed that satisfactory fatigue characteristics can be achieved by painstaking attention to detail design while fully exploiting stretch testing.

(*d*) *Status of Loads*—Stretch testing is of questionable benefit unless there is good reason to believe that the design loads for the various components are quite accurate. This means that the expected usage of the airplane has been realistically assessed; the loading conditions associated with this usage correctly defined; the methods for breaking down overall loading conditions into shears, moments, and torques have been based on sound aerodynamic coefficients and spatial distribution of these coefficients; and all other significant effects, such as dynamic loadings and aeroelastic effects, have been properly accounted for. It is a major calamity to find that, having spent hundreds of hours of analysis squeezing overweight (and the corresponding strength) out of a component, a load re-evaluation indicates the basic strength is far too low. Balanced engineering effort should keep all factors at something like the same degree of accuracy.

Reliability of loads calculations suffered considerably during the recent period of aerodynamic uncertainty accompanying transonic airplane design, but these problems are now under fairly good control. There has been a great amount of data collected recently defining the characteristics of service operations from the standpoint of rational loading conditions. Much work has been done recently in the measurement of loads in flight, and activity in this field is increasing. The writer believes that load calculations now have a sufficiently sound scientific basis to warrant the general use of stretch testing.

Conclusions

Stretch testing has actually been in general use on aircraft structures without having a great deal of attention directed toward its full exploitation. A design procedure is outlined for this purpose. It is shown by several examples that stretch testing has resulted in worth-while strength increases with small weight expenditure. For cases in which the timing of tests and production run allow it, the stretch-test procedure is recommended as an extremely valuable tool in developing structurally efficient aircraft.

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(*Continued from page 53*)

conducted by the NACA. Mr. Bridgeman, who acted as test pilot for this project, presented his impressions of the airplane from his first acquaintance with it, when he decided that "someone has slipped a cog," to his final impression that "at delivery (to the NACA) we had a very flyable airplane."

Comments were presented by Dr. Hugh L. Dryden of the NACA and Clarence L. "Kelly" Johnson, Chief Engineer, Lockheed Aircraft Corporation, Burbank Division. Dr. Dryden's comments dealt with the research aspects of the airplane, and Mr. Johnson's comments were concerned with the general approach of research aircraft as a testing tool.

With the closing of this session, which had run to a fairly late hour, the 1954 National Summer Meeting was concluded.

Practical Expectations and Limitations of the Reliability Problem

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Introduction

THE GREAT EMPHASIS that is rightly being placed on the urgency and seriousness of the reliability problem has given rise to numerous papers on one or another of its many aspects. The tendency has been for each author to stress his own particular interest or problem with little or no attempt to give it its proper dimensions or to establish its relationship and its limitations in the overall picture into which it must fit. This is a very natural condition, since the problem is both immense and complex, and each man necessarily deals primarily with his own part of it. As a result, there is a growing need for a better balanced and integrated viewpoint, at least to the extent that the great variety of subjects concerning reliability be more accurately appraised relative to the practical necessities for putting them into effect in the widely different circumstances where their application may be considered.

The purpose of this paper is to attempt such a correlation among certain timely proposals, projects, or expedients which currently occupy the reliability picture. Because of the great size of the problem, the treatment of each subject must necessarily be limited if the scope is to be reasonably broad. But if there is any one conclusion on this matter which may be emphasized at the outset and which stands out more than any other, it is the all-important fact that inherent equipment reliability alone, however good, is not enough. The picture of continuing reliability under the vicissitudes of a lifetime of effective service, whether long or short, is far broader. It involves shipment, installation, testing, operation, maintenance, and the reliable planning, coordination, and execution of all of these functions, the shortcomings of any one of which may defeat any project otherwise blessed with equipment 100 per cent reliable in itself. In short, all of these things occupy a vital position in the reliability picture.

Because the practical value of any reliability proposal bears a direct relation to the stage of development of the project in which it may be applied, a division of such proposals into "short-range" and "long-range" categories affords valuable distinction and clarification: short-range when applicable to existing projects well under way, where no new proposal is ordinarily admissible unless it avoids major disruptions of existing plans and schedules; and long-range when limited to new projects and new planning, where time must be allowed for adequate development of the new features that justify the undertaking.

The subjects to be considered are classified into these two groups, though in some cases, as will be evident, the division is not sharp, but rather a matter of degree.

Among the subjects deserving consideration in the short-range category are the following:

(A) Short-Range Category

(1) Test-to-Failure

This subject has lately received an exceptional amount of attention in the literature but without sufficient emphasis, it is believed, on its difficulties and limitations and on the resulting need for judicious and selective application, particularly for short-range purposes. Test-to-failure is a useful procedure, but practical problems tend to limit its profitable field of usefulness. It is a valuable tool, but not a cure-all. Suppose that we are engaged in a missile project. We employ a great many products of other manufacturers as well as our own, we have a variety of difficulties with problems of unreliability, and, worst of all, we are in many cases not too sure why. That should not be an unfamiliar situation to imagine. Very acceptable is the thought that it would be a great help in this situation if we could test all of our component parts to the point of failure or if we had the information on how and to what extent they reflected the results of such tests by others and, thus, could proceed more intelligently to improve reliability. But how could we go about it? We have in front of us a big contraption full of thousands of pieces and parts in great variety. In order to avoid a test program that is nothing short of stupendous and quite beyond the remotest practicality for reasonably short-range purposes, how do we decide, starting now, which component parts are unreliable enough to require test to failure or further test of any kind? And who shall test them? In the case of another manufacturer's product, how shall we persuade him to make further tests, and how shall we determine what the nature of the tests shall be? And how shall we handle the problems of increased cost and delay in delivery? Furthermore, are we dealing only with component parts? Why not subassemblies or even systems, with the same questions asked again?

Some impressive examples could be cited here to demonstrate the difficulties that arise in attempting

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to answer some of these questions—such as, for instance, trying to get a manufacturer to change his established practices in order to improve his product, particularly if he manufactures a small item in large quantities and if his other customers do not happen to be complaining at the time. But, for the sake of brevity, the examples must be omitted. Suffice it to say that the going is hard and that a great deal of time and effort may easily be expended without significant progress.

It seems plain that the problem cannot be approached in this wholesale manner, if we have any hope to see it finished. In this form it is surely not short-range and is most likely too cumbersome to be practical even on a long-range basis. The crucial point is that test-to-failure stands or falls upon the validity of the test conditions as compared with service conditions. This is obvious enough, but the difficulties arise in putting the thought into effect.

Test-to-failure as an indicator of suitable reliability in service necessarily means test under conditions more severe than those that occur in service, where it is of course intended that failure shall *not* occur. This presupposes a reasonably accurate knowledge of the conditions existing in service in all of the important respects which can lead to failure. Otherwise, it would not be possible to aggravate or intensify them to a measurable degree, or to establish a relationship between test results and performance to be expected in service. This fundamental principle is quite simple to apply in a few cases, but difficult to the point of impossibility in many others. A few examples may be useful.

In the realm of comparative simplicity may be placed a wide variety of temperature requirements. In general, dealing with temperature alone, it is a straightforward procedure to establish a margin of safety over an expected maximum temperature in service by establishing satisfactory performance at a higher test temperature. Unfortunately, few cases are so simple.

On the more difficult side we have shock and vibration. Apparently not too formidable at first glance, the problem mushrooms in complexity when studied. Just what are the conditions of vibration and shock which occur in a missile? We must know them to begin with if we are to intensify them intelligently for test-to-failure. Since in fact we do not know them nearly well enough, we can only apply test conditions somewhat blindly, with the result that an excessive margin of safety may be specified for one type of vibration while an inadequate one is permitted for another. More specifically, vibration tests may be run on a relay over a wide range of frequencies, with the relay in a variety of different positions. The relay may withstand the tests satisfactorily, yet might fail readily in the missile if subjected there to vibration that is torsional because the test vibrations were practically everything *but* torsional. It may be noted further in connection with torsional vibration that its effects in any one location in a device are usually manifested with respect to an axis of well-defined and fairly constant position. Consequently, a mere change of mounting position of a component that shows detrimental response to torsional vibration may completely cure the trouble.

A particularly vital fact to be recognized in setting up test conditions that can reliably simulate and intensify actual service conditions is the necessity for employing realistic *combinations* of hazards rather than hazards applied *singly*. Hazards are largely simultaneous in service and interact in many cases to produce results incapable of occurring from the same causes operating separately. This fact is now generally recognized, but test facilities have not kept pace. It is not yet by any means a simple matter to produce a combination environment for test purposes, even if one is fortunate enough to know what environment he would like to have.

This same necessity for authentic duplication of service conditions leads to other requirements frequently overlooked. It is not only the combinations of hazards of various intensities which are important but also their duration, their respective rates of change, and their past history or the number of times they have previously been applied. The relative importance of these factors necessarily varies with each specific case under consideration. However, certain general cases may serve to emphasize the point. It has been demonstrated, for example, that the combination of high temperature and high humidity is usually more detrimental than either one alone, also that long continued exposure to either one may have permanent weakening effects. It has been shown that the effects of temperature extremes may be seriously aggravated in the presence of shock or vibration, while the possibility of permanent fatigue effects from numerous types of mechanical manipulation is well known. The filament life of a vacuum tube may be reduced and the operating characteristics changed to a much greater extent by repeated turning on and off than by a single application of filament power for an equivalent period of time. This short review of examples is intended to emphasize that test-to-failure means one thing in one case and usually something else in another and that the establishment of test conditions that are truly representative of service conditions may be no mean achievement, particularly for missile purposes where no pilot ever goes along and returns to tell the story.

Without belittling the good results that may be accomplished by test-to-failure procedures in those cases where the connection between test conditions and service conditions can be satisfactorily established, it seems desirable to sound a note of caution to the effect that, even on a long-range basis, many other cases may be found where this particular avenue of approach to reliability is too unwieldy, time-consuming, and expensive.

This may seem like a somber conclusion, but unfortunately there are not too many easy answers foreseeable in the reliability problem. It is too far-reaching, too complicated for that. Actually, it is in itself a long-range problem—one in which the working out of the

essential processes to find the right answers takes considerable time. Our electronic equipment today, from the long-range viewpoint required for the development of reliability practices, is still essentially in its childhood. However, justification for an optimistic outlook for the future reliability of electronic equipment is not hard to find. The recently announced definite undertaking of the first transatlantic telephone cable may be cited. The numerous repeaters embodied in this cable are expected to operate for an indefinitely long period on the bottom of the ocean with little likelihood of trouble that would necessitate the expensive operation of raising the cable to repair them. And these repeaters contain vacuum tubes, which as a class are our number one culprit! Also, in connection with present standards for the equipment associated with dial telephone systems, the following is quoted from the *Bell System Technical Journal* for January, 1954:

"Reliability required in telephone switching systems would be considered unreasonable in many other types of equipment and can be judged from the fact that a single failure in 5,000,000 operations is considered to be poor performance.... Stated another way, satisfactory operation for the average relay in modern telephone switching systems is less than one failure in 40 years of operation....In these systems, establishing a single telephone connection between two subscribers makes use, for a very short time interval, of approximately 1,000 relay operations with a total of about 7,000 contacts."

When we have that kind of reliability in intricate and complex equipment that we all use every day on a country-wide basis, we have little reason to doubt that our own problems will eventually be solved. The telephone system is an excellent example of a long-range development that has necessarily been reliability-conscious from the start, and where the immense persistent effort necessary to achieve such a result has had time to accomplish its purpose.

(2) *The Case for 100 Per Cent Testing of Service Units*

It is obvious that test-to-failure is a process for establishing design requirements, since the units tested are usually destroyed in the process. To assure the quality of units produced in the manufacturing process and intended for service, some form of testing which is less severe is, of course, required. It is here that statistical quality control enters the picture with sample testing and employs the laws of probability to show that the quality of a large lot of units in terms of the probable number of defectives can be established to any desired degree of accuracy by tests of a certain specified number of random sample units. For most purposes, sufficient accuracy is attained by a group of samples which is only a small percentage of the total number of units. However, it is now our purpose to see what happens to the usefulness of sample testing as the permissible incidence of defectives becomes very low, or as the required reliability becomes very high.

Any complicated electronic system, whether a bombing-navigational system in an airplane or the guidance system in a missile, employs so many component parts that, for the kind of high overall reliability we have any hope of ever attaining, the reliability of individual parts must be fantastically close to 100 per cent. For such an objective, sample testing is not good enough and the advantages of statistical quality control disappear. Two examples will illustrate why. In the first example we will permit 1 per cent of defectives, or 99 per cent reliability, in a large lot of, say, resistors. Without spending much time on the details of the mathematics, we may say that in a lot containing 1 per cent defectives it is not very unusual to get as many as three defectives in a sample of 100. So we accept any lot showing three or less defectives in such a sample.

But we must instantly admit that no such lax standard as 1 per cent is permissible for resistors, condensers, or any other simple component used in great numbers. Let us say that we must have only 0.1 per cent defectives. Even that figure is hopelessly high for component parts if we aim, for instance, for even as many as 9 out of 10 good missiles embodying thousands of parts. But let us use the 0.1 per cent defective figure. Our second example then requires us to rephrase our story to the effect that in a lot containing 0.1 per cent defectives it is not unusual to get as many as three defectives in a sample of 1,000. The result is that, if we must test 1,000 samples in order to establish that not more than one per thousand is defective in a much larger lot, we are making far more tests than missiles or airplanes, and we might just as well abandon any thought of sample testing and merely say that we intend to test every component that we use. We are then taking no chances that there are any defectives, *at least as far as that particular test is concerned.*

The above clause is emphasized because it is important to point out another respect in which sample testing becomes increasingly unreliable as the permissible percentage of defectives becomes very small. The test procedure must necessarily be set up to catch the failures that are normally to be expected from generally known and predictable causes in the manufacturing process. If the permissible percentage of defectives is not too small, the defectives discovered by the test procedure are a large percentage of the *total* defectives, including others present from random causes not capable of being recognized by the test. In other words, the defectives disclosed by the test are in this case a large enough percentage of the total defectives to permit considering the random failures negligible. If, however, the percentage of defectives must be forced extremely low, then the test procedure may become inadequate because the defectives of the predictable type that it discovers are no longer a large part of the total defectives. Random failure from comparatively unpredictable causes thus looms relatively large and becomes the limiting condition, rather than the causes of failure which that the test procedure is designed to catch. Unless the test procedure can be modified and

broadened to cope to some extent with random failure, no further improvement in reliability is possible.

In the case of a simple component such as a resistor, it may be that the possible causes of random failure are few enough to be negligible or, if not, then at least readily capable of discovery by test procedure. However, the problem rapidly becomes more difficult with more complex items. We are personally familiar with a monumental case of random failure where a vacuum tube socket broke down between tube pin holes because of a small piece of metal imbedded in the insulating material.

Nothing that has been stated is intended to question the practice of employing sample testing as the basis of acceptance or rejection of large batches of component parts merely for stock purposes, so long as it is understood that all units should be subject to individual test before use.

It is suggested that carefully planned test procedure for 100 per cent testing, at suitable factors of safety, not only of component parts but also of all crucial functions at progressively higher levels of assembly, may be a vitally necessary step in dealing with all types of failure, including random. In the case of parts manufactured by automatized processes, attention seems warranted to the development of 100 per cent automatic test procedure as an integral part of such processes, so that the finished product does not even appear at the end of the line until it has been tested.

The case for 100 per cent testing has been stated primarily for short-range purposes, where it has its greatest immediate value and is usually, in fact, imperative. However, it will clearly be necessary to continue testing until the quality of each component has improved to such an extent that further test becomes unnecessary. One cannot fail to observe, in passing, that when it is essential for a purchaser to test each individual item as it comes from the manufacturer in order to establish that it will do what it is presumably supposed to do without such test, we have a highly inefficient and unnecessarily costly procedure that is badly out of joint. Adequate tests should be performed at one point or the other and not duplicated. The only reasonable exceptions to this rule are (1) in the case of shipment of fairly complex assemblies, where a substantial possibility of damage has intervened and (2) where doubtful shelf-life introduces the hazard of deterioration.

(3) *Principal Efforts on Worst Offenders*

No study of the possibilities of improving overall reliability in any complex device can go far before encountering the fact that a proper distribution of emphasis and effort necessarily demands principal attention to the worst offenders. This is not a matter of choice but a fundamental principle of reliability. Consider vacuum tubes as an example. As long as tubes as a group are the worst offenders and are far out of line with other components, improvement in tubes or the development and use of suitable substitutes are the only ways to accomplish important improvement in overall reliability. This does not mean that improvement of other components should be neglected or that we should delay other important problems until the vacuum tube problem is solved, but it does mean that, if all the tubes in an airplane are only 85 per cent reliable as a group for the required duration of flight, then it is impossible for the overall reliability figure to be better than 85 per cent, even if all the other components are 100 per cent reliable. This is, of course, true only for hazards that are effectively in series from the reliability standpoint like the links of a chain. However, that is the case for most of the malfunctions that can occur in an airplane and for practically all that can occur in a guided missile. In other words, only if and when vacuum tubes are brought to the same general level of reliability as other components will it be realistic to apportion the effort at improvement somewhat equally in all directions.

It must not be overlooked in dealing with worst offenders that the component that fails to do its own job properly is not the only problem with which we have to contend. We have also the situation where improper design or environment calls upon a component to do more than it is intended to do, and this is the more difficult of the two to handle. It is not only more careful design that is called for but also the feedback of information on poor performance. These are essentially long-range matters and are given further attention later.

It is important to note, finally, that the search for reliable substitutes for worst offenders is a profitable short-range expedient. The substitute has many times turned out to be better than the original. A case in point is the rapid development of transistors and their invasion of the vacuum tube field.

(4) *Redundancy*

One of the important short-range measures which may be employed in one form or another to improve reliability is redundancy. This name applies to any one of a great variety of arrangements which may be employed to make a device or a system self-checking, self-correcting, self-sustaining, or in any manner less susceptible to the effects of a malfunction. The additional equipment provided for this purpose is superfluous or redundant as long as normal operation continues but performs its services when trouble occurs.

There is abundant evidence that the simplest and most profitable applications of redundancy have not been generally appreciated or exploited in air-borne electronic equipment. Yet in the airplane itself we have one of the best examples of its application in the fact that there are from two to eight engines, only the smallest planes being limited to one. One of the important reasons for this is to reduce to negligible proportions the probability of a major catastrophe if an engine fails. Neverthless, on any multiengined military plane you will probably find electronic equipment containing

numerous relays with single pairs of contacts, or even worse, numerous single pairs of contacts in series.

A single pair of relay contacts, constituting a single point at which a circuit is closed or opened, is by no means the most reliable device in the world. Ordinarily, the chance of failure of the contacts to open is negligible, but failure to close or to "make" contact occurs often enough to be a problem. Yet nowhere can great improvement in reliability be bought more cheaply than by providing two pairs of contacts in parallel. In practically all types of relays this modification can readily be adapted to the existing form of the relay without increase in overall size and without reduction in available facilities on the relay. Since contact pressure is not critical unless submarginal to begin with, the probability of contact failure for two contacts in parallel approaches the square of that for one contact, even without changing the power of the relay. In other words, if the probability of failure of a single contact is 1/100, corresponding to a reliability of 99 per cent, the probability of failure of two contacts in parallel approaches the square of that for one contact, or 1/10,000, with a reliability of 99.99 per cent. If many contacts in series are required, this kind of reliability insurance at each contact point is practically imperative.

There has been considerable controversy on the subject of redundancy, apparently largely as a result of misunderstanding. There can be no serious question raised as to the great advantages realized from relay contacts in parallel. At the other extreme, the provision of a spare or redundant gyro in a bombing-navigational system might be proposed, which would require the further addition of a sensing device to determine when it was necessary to substitute the spare for the regular. The sensing device would introduce the question of its own reliability, to say nothing of weight and space requirements, and the whole scheme would probably fall, both literally and figuratively, of its own weight.

But between these limits lies a field for the investigation and application of redundancy which may well turn out to be very fruitful. Furthermore, the tightness of the various limits against which we shall undoubtedly find ourselves straining before the reliability problem is solved is very likely to force us into greater use of redundancy. It has already been pointed out by Carhart,* of The RAND Corporation, that when stiff practical limits on both complexity and component reliability have been reached, redundancy offers the *only* means for further improvement in reliability.

We now come to the long-range category and it is here that the hard facts of the situation really come to light. Let us start with what may well be regarded as the worst aspect of the problem—one that should make us wonder how much time we have and how close our backs may be to the wall—namely, maintenance requirements and costs and their relation to first costs of electronic equipment.

(B) Long-Range Category

(1) Proper Balance Between First Cost and Cost of Maintenance

If we consider the obvious fact that electronic equipment is absolutely essential for combat effectiveness, we are immediately forced to admit that maintenance requirements on the present scale could not be met in time of war. We can therefore feel certain beyond doubt that combat effectiveness would be critically hampered by inoperative equipment. Carhart, in the same reference previously cited, quotes electronic experts to the effect that "military electronics would require several times as many men as would be available in the event of war." In the same document is given the rough estimate that one electronic technician is required for every 250 vacuum tubes and that, on this basis, one aircraft carrier with about 12,000 tubes would require 50 such maintenance men. That the maintenance problem on the basis of present experience is entirely out of hand is illustrated in another way by the supply problem. The worst of the bad actors is, of course, the vacuum tube. For every tube operating in its socket, about nine others must be in consecutive stages of the process of moving in as replacements.

Needless to say, the cost of maintenance is correspondingly out of hand. It has been determined, also by RAND, that Air Force maintenance cost for electronic equipment is about twice as much per year as the first cost of equipment. The Navy's estimate of maintenance cost during the life of the equipment as ten times first cost is substantially in agreement. The magnitude of the figures involved becomes evident when it is noted that about 4 billion dollars were spent for all military electronic equipment in fiscal 1953. Plainly, then, vast sums of money would be saved by significant improvements in reliability, even at an increase in first cost by a factor of 2 or 3. Doubtless we shall some day arrive at the point of diminishing returns, where it will no longer pay off to push reliability higher and maintenance lower, but we are a long way from that point today. Some authorities have gone so far as to set a goal of *no maintenance whatever* during the expected life of the equipment. Such a radical objective is probably not generally possible within reasonable limits of time and expense, but the important point is that significant advance in that direction will undoubtedly pay for itself many times over.

Improvement of this nature plainly implies new design, and new designs must, of course, be undertaken. But there are also certain hard facts in that direction, as we shall see.

(2) Simplification

It is a rather obvious and fundamental fact that increased complexity reduces reliability. Indeed, there is no denying that it is the great increase in complexity

* Carhart, R. R., *A Survey of the Current Status of the Electronic Reliability Problem*, The RAND Corporation, August 14, 1953.

of electronic equipment which has presented us with unreliability in direct proportion, there having been little or no change in the meantime in the quality of components or the wisdom of their application to disturb the simplicity of this mathematical relationship—at least not until the problem was already upon us. Military electronic equipment may at present be said to be at or near a point of critical complexity, corresponding to a point of critically poor reliability. Further degradation of overall reliability is clearly not permissible; on the contrary, improvement is generally conceded to be imperative at the present level of complexity.

Yet it is equally clear from several readily predictable courses of events that it will not be possible to accomplish a *net* reduction in complexity. Let us agree that some of our hardware will be redesigned for simplification, that the same functions will be performed by simpler equipment more cleverly designed, and that functions will be reduced to those that are indispensable and include none that are only moderately useful or merely convenient. Let us even agree that the military services will all consent, as the Navy has already done in certain cases, to the narrowing down of the field of application of a device, thus requiring two somewhat different devices to cover the field previously covered by one, but permitting reduction in variety of functions, in complexity, in size and weight, and in number of controls and, *above all*, permitting an increase in reliability.

Let us assume that we shall accomplish a great deal of this kind of streamlining, as indeed we should. However, any such achievement is sure to be overbalanced by the introduction of new hardware. Our inventors and our research and development laboratories will still be making new discoveries and dreaming up applications of them for bigger and better accomplishments. We may depend upon it that the new devices will be sufficiently attractive to preclude their rejection. At the same time, it may be accepted as absolutely certain that the maintenance problem will defeat the very objectives sought unless the evidently unavoidable net increase in complexity, whether in an airplane, a guided missile, an aircraft carrier, or a submarine, is *more than* compensated by improved component reliability throughout all of the electronic equipment installed and by improved overall reliability resulting from better design and construction in all respects.

It is readily seen that the build-up of pressure for the accomplishment of these ends is tremendous. Though first costs will undoubtedly rise, we have already seen that this is justified, provided that the requirement of reduced maintenance is met. But how much time have we? I do not know that any more than you. If we were sure we had a great deal of time, the picture would not be nearly so disturbing. We have satisfactorily reliable complex devices all around us in everyday life, and I have no doubt whatever that we can accomplish the same result with air-borne electronic equipment, if we have time. We are considering some extremely vital matters on a long-range basis. We may well hope that we shall not have them thrust at us on a short-range basis, whether we are ready or not.

(3) Feedback of Failure Information

The importance of saving time suggests the need, which is still generally prevalent, for immediately reporting back to manufacturers and designers the shortcomings of their products in service. Nothing builds confidence in a product more effectively, no matter how superbly designed and manufactured it may be, than the sure knowledge that it has been through the fire of service conditions and that its faults have been smoked out and remedied. This refers primarily to the finished product, though the same process has great value during development as well, in which case it must be reasonably short-range. All too often no effective procedure has been set up to obtain trouble information accurately and completely and to see that it gets to its proper destination quickly, with the result that large quantities of the product which might have been held for correction of faults have already been shipped. Shipped with them is an added maintenance and reprocessing problem.

We have here a strong restraining argument against too much stockpiling, particularly in the case of comparatively new and insufficiently proved devices. The troubles present in such accumulated stock are stored away for future discovery at a more inconvenient time.

Much of this has been said before; in fact, a number of extensive feedback programs are at present in operation. But the matter is emphasized here because it is far from being exploited in all useful quarters or to the optimum extent, and because too little emphasis has been put upon making it more speedy and thus realizing the marked advantages of early discovery and remedy of troubles. Unfortunately, it is now usually a rather long-range operation that should be effectively shortened in every possible manner.

It was emphasized in the opening paragraphs that equipment reliability, however good, is not enough, and we have still to consider certain other factors that justify that statement. Because the scope here is so broad, we can give attention to only a few of the most important. We shall therefore have to assume at this point that we have made great progress toward our goal as far as inherent equipment reliability is concerned and that all of our black boxes of hardware, while not perfect, have shown themselves capable of a satisfactory job under service conditions. It will also be necessary to assume that certain other long-range items that deserve our attention have somehow been miraculously taken care of, so that adequate instruction books for operation and maintenance of the assembled black boxes have been provided on time; that test equipment designed for the purpose or at least properly selected and adapted to the purpose, has been provided at convenient locations; and that qualified personnel have been trained and are available for both operation and maintenance. It may seem that this is all so close to

the arrival of the millenium that it is presumptuous to ask if it is enough. But the answer must emphatically be that it is not. Reliability is suffering acutely today from inadequate system planning and from inadequate coordination and cooperation between widely separated organizations working on different parts of the same project, and it is to these subjects that we shall now limit our consideration. They are closely related and their influence is so broad that they affect many of the items we have already considered. They stand strategically at the head of the list of long-range reliability problems, and are slow and difficult to handle because they readily become involved with organizational incompatibilities and matters of policy requiring attention at administrative levels. Nevertheless, the need for improvement must be more generally realized before the resulting heavy penalty against reliability can be withdrawn.

(4) *System Planning*

"Project Reliable," starting roughly four years ago, was the opening gun of the reliability compaign in which we have been engaged. Practically the first bad situation that was brought to light at that time was the discovery of electronic equipment unhappy in an environment it was never intended to endure. The gear had not been designed into the airplane; it had been more or less poured in. A typical trouble was excessive failure of vacuum tubes operating in a hot spot with insufficient air circulation. In short, system planning had been very inadequate.

Though there have been outstanding instances of improvement since that time, the problem is still with us. Neither the military airplane nor any other complex weapon will ever have the reliability and operating efficiency it so sorely needs until it is adequately planned and engineered as a system, including all of the gear that goes into it. There is no substitute for expert integrated supervision and control of any large project, least of all a military airplane or a guided missile project. I am anxious to avoid entering too far into controversial territory, and it is even probable that in my own company considerable difference of opinion exists on this point. Nevertheless, it seems clear that one of the most fundamental requirements for ensuring the coordination of planning with effective continuity of policy and experienced management is that a qualified civilian organization, rather than a branch of the Armed Forces, should exercise the function of prime contractor. Such a prime contractor should have full authority to deal with subcontractors for the furnishing of all types of equipment required, both electronic and otherwise, and should be fully responsible for meeting the performance requirements specified. Needless to say, such an arrangement does not in any way avoid the need for the fullest cooperation with the branch of the Armed Forces concerned but does, in may respects, afford a clearer and more effective division of responsibilities.

One of the handicaps under which airplane manufacturers have frequently been constrained to operate in the effort to assemble an airplane as a workable system is the necessity of employing certain specified types of equipment, known as G.F.E. or Government-furnished equipment. Effective system planning does not always readily accept such equipment, and it is felt that a prime contractor should have a free hand in this respect also and should be permitted to reject any such equipment that, for good reason, he finds incompatible.

(5) *Coordination and Cooperation Between Widely Separated Organizations*

It was stated above that there is no substitute for expert integrated supervision and control of any large project, and it should now be added that the larger the project and the more numerous and widespread the organizations contributing to it, the more vital such supervision and control becomes. Reliability throughout the devious and complex operations of such a network is a far more difficult thing to achieve than reliability in a complex mechanism. At least the parts of the mechanism stay put, and if you stop studying them to go out for lunch, they will still be there when you come back. But human organizations are mobile, almost as much so at times as the individuals who compose them. The one thing that can be depended upon is that they will *not* stay put; since the possibilities of movement are practically infinite, the probability is overpowering that without adequate supervision and control the right move will not be made. When the soldiers in the parade fail to hear the band, they get out of step. It is, in fact, only the most ordinary human failings that are responsible for most of the confusion, misunderstanding, and working at cross purposes which too frequently occur in the operations of any far-flung enterprise.

Adequate supervision and control are the only answer we can possibly devise for this trouble. It was my own unfortunate experience during World War II to be associated with an important project, involving widely separated organizations and requiring their effective cooperation, where the supervision and control were permitted to demonstrate their importance by the effects of their absence. It was not a pleasing spectacle, nor an exceptional one, during war. Yet, we have too much of the same kind of thing in time of peace, without the excuse of war to explain it away.

Obviously, we must have the single responsible organization at the head and then adequate liaison on a continuing basis. The channels of operation must be regular and familiar. The newness and unfamiliarity of such channels are largely responsible for the greater confusion and unreliability that seem unavoidable during wartime.

With such effective supervision and with all of the improved means for communication at our command today, we should surely be able to accomplish a great deal at building reliability into the related functions of our organizations, as well as into our equipment, and thus create the kind of balance among all factors of the reliability picture which is so essential to success.

Application of

Operations-Research Techniques to Air-Borne Weapon System Planning

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Introduction

There is a traditional and time-honored cartoon that has hung on the walls of aeronautical engineering departments for many years. (See Fig. 1.) It depicts the airplane as seen through the eyes of the different specialist groups that contribute to the conception and birth of an aircraft.

You have all seen it and remember it well. It suggests humorously that these various specialists have a somewhat distorted view of the importance of their special province in airplane design. The wing group sees the airplane as all wing; the weight group wants it made of balsa wood and microfilm; the production engineer wants to turn it out like Sears Roebuck fences; the power-plant group sees a flying engine with certain necessary but inconsequential appendages, etc. Now most of these engineers will admit that, miraculously enough, after suitable bludgeoning by the preliminary design engineer, the project engineer, and the chief engineer, a flyable airplane results. In fact, it usually turns out to be a pretty good airplane in spite of these diverse points of view.

I have taken the liberty of altering this standard work of art to suggest that something new has been added—the operations-research or operations-analysis group. This group sees the airplane, the logistics that support it, and the operations it performs as a total system or entity. This group numbers among its members aeronautical engineers who are no longer infatuated with the romance and joy of design itself but have begun to ask such questions as: "Why are we designing this airplane in the first place?", or "When viewed as a total system, is this the best that the state of the art can produce?"

In this paper I shall discuss the reasons why groups of this type have been or are being formed in nearly every aircraft company and in the military services. I also want to discuss the methodology involved and some of the lessons that have been learned in the 5 years' existence of such a group at the Lockheed Aircraft Corporation.

Although the paper refers primarily to military aircraft systems, one need change only a few key words such as "airplane" and "enemy" to, say, "mouse-trap" and "competitor" to make it applicable to many industries.

The air-borne weapon system planners of today, whether in industry or in the military, are continually confronted with the making of the most complex decisions ever faced by any military planner. This complexity stems not only from the tremendous rate of technical progress in weapons, vehicles, and equipment of the last decade, but also from the multiplicity of possible solutions that now exist for many military missions. As a simple example, consider the bombing problem. In World War II we had the reciprocating engine, the TNT bomb, and overseas bases. Contrast this with some of the possible alternatives for bomb delivery in the forthcoming decade. The power-plant spectrum has now been increased to at least six, as shown in Fig. 2, with the addition of turboprop, turbojet, ram-jet, rocket, and nuclear power plants for propulsion. In addition to conventional bombs, there is the atom bomb and perhaps even more powerful weapons. Operations may be conducted from overseas bases or from within our zone of the interior. In Fig. 2 we see 24 combinations derived from base locations, power plants, and destructive loads. The total of possible alternatives does not end here, however; the range is tremendous. Its limits can be partially appreciated when we consider that each combination of base, power plant, and bomb can generate an entire spectrum of possible aircraft having different configurations, speeds, ranges, military loads, operating altitudes, offensive and defensive capabilities, delivery accuracies, and cost. In addition to delivery by conventional bomber, there can be delivery part way by bomber and the rest of the way with a missile or all the way by pilotless aircraft or long-range ballistic missile. Delivery may also be achieved by launching piloted aircraft or guided missiles from submarines.

Importance of Weapon Systems Planning

The quantity production and logistic support of any of these systems require expenditures of considerable fractions of our national armament budget. For example, a single wing of heavy jet bombers costs nearly a half billion dollars to buy and 80 million dollars a year to operate. Of perhaps even greater importance, the time scale of the next war will undoubtedly be such that we may be denied the opportunity to produce a replacement for an inferior weapon system selected 5

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* Director of the Military Operations Research Division, California Division.

to 8 years previously. It is interesting to conjecture the effect on the outcome of World War II if Hitler had committed that fraction of his resources spent on building 6,000 V-2 rockets to larger production of the lethal twin-jet ME-262 fighter to counter our strategic bombers.

The foregoing is a clue to the magnitude of the problem facing the weapon system planner. Thus, he may be less concerned with what is technically possible to build than what is required in order to maintain the national security at an affordable cost. Which of these weapon systems, or combination of systems, does he select for maximum efficiency? What are the basic design characteristics of the best systems? The process of selecting the proper systems for development and procurement is filled with grave and far-reaching responsibilities. Clearly, there is need for aid to the process of decision in future air-borne weapon systems planning. Indeed, here is an important, challenging, and intriguing task for the scientist, the engineer, and the tactician.

The Aircraft Industry's Problem

Let us examine the problem from the aircraft industry's point of view and review briefly the origin and development of a typical military airplane model. In general, there are two sources for the original design of the military airplane. First, it may have been submitted to the military by one of the aircraft companies, reflecting their ideas of a good airplane for some particular job. On the other hand, the basic specification may have been formulated by military planners and requests for bid proposals circulated to aircraft companies through the proper procurement bureau. In either case, an experimental—and sometimes a production—contract is let, and the selected company proceeds with design, development, testing, and production of the models.

From conception to operational status in quantities, the time required for an entirely new aircraft design may vary from 4 to 8 years, depending on complexity and urgency. Fighters, for example, might reach combat wings ready for combat in 4 years, whereas

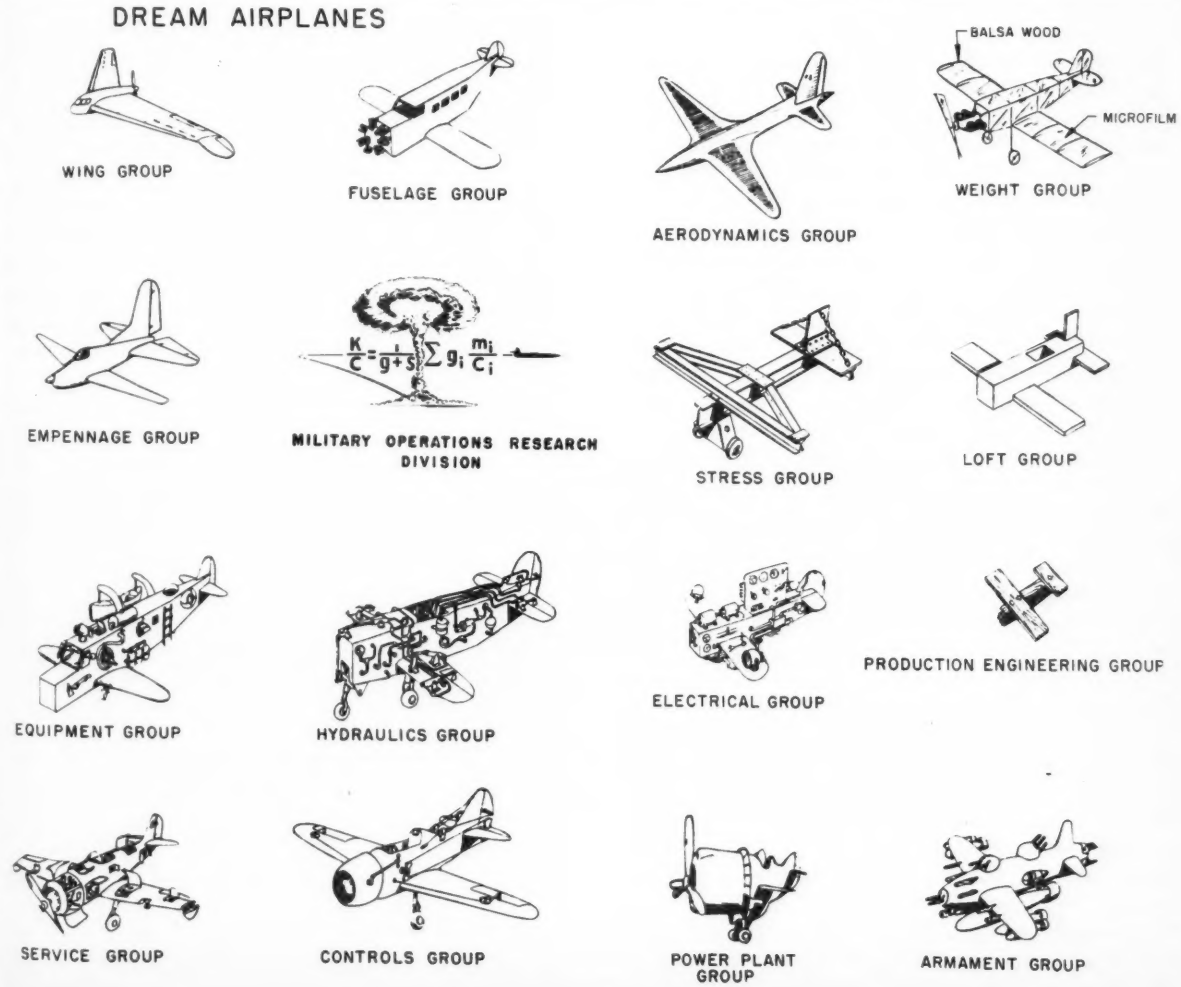


Fig. 1.

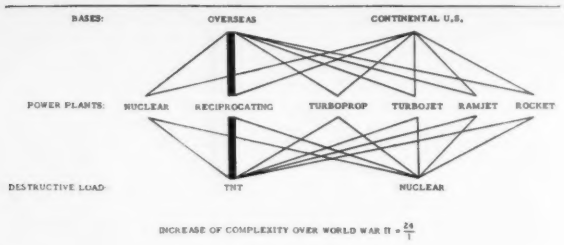


FIG. 2.

FIG. 3.

medium and heavy bombers may take as long as 8 years or more to reach operational status in quantity.

Because of the very nature of aircraft, once the basic specifications setting forth speed, range, pay load, etc., of the airplane have been determined, the configuration is established, and little can be done to change these characteristics during the development stage. Although it produced many fine aircraft, this traditional process has also produced a great number of prototype aircraft that have cost large sums of money and much highly skilled man power but which were never produced in significant quantities, if at all. Presumably, in someone's opinion, these were unsatisfactory or unwanted aircraft. They will be found throughout the industry; both military and commercial types are represented. In fact, historically, these aeronautical curiosities far outnumber the airplanes that have received full implementation.

One must, of course, except from these discussions experimental aircraft designed merely as test vehicles. Most of these discarded aircraft flew well, were sound structurally and aerodynamically, and could be produced efficiently in quantity. Yet, as systems, they have presumably failed. Where was the error made by the original planner? Hastening to his defense, we must first note that, to add to his confusion about the job to be done or what the military may want, there are several factors under his own control. For example, we see the variations in airplane size for a particular type which arise from changing only the military load, if a speed of 200 knots and a range of 2,000 nautical miles are desired (Fig. 3). Conversely, for a fixed military load, we note the variation in size for changes in cruise speed and/or range (Fig. 4). Nothing has been said in this example of the relative cost of these systems, of the changes in capability with military load, or of a host of other pertinent factors.

We now see the plight of the planner of military air-borne weapon systems. He is faced with the necessity of making virtually irrevocable decisions on the basic specifications of an airplane 5 years or more in advance of its combat usage. This places exacting requirements and a heavy burden of responsibility on the executive. Failure results in large-scale waste and produces an inferior weapon. In wartime, the losses in money and lives from facing the enemy with an inferior weapon may far overshadow the previous waste. What, then, are the requirements for proper initial selection of the aircraft design, the bases for choice, and the methods for providing the correct answers 4 to 8 years in advance of the operational use of an air-borne system?

Application of Operations-Research Techniques

It is firmly believed that the methods and techniques of operations research, adapted, extended, and applied to the particular requirements of air-borne weapon systems analysis, can produce the necessary aid to decision. Although systems analysis has been practiced for years in various industries, the complexity of the problem under discussion appears to call for skillful application of every tool the operations researcher has available, plus as many more as he can devise to achieve the required objective. "Operations research" may mean many things. It has been defined by Kimball and Morse as "a scientific method of providing executive departments with a quantitative basis for decisions regarding the operations under their control." This implies the observation and analysis of current operations, or parts of operations, which make them amenable to scientific attack and solution.

In most of the classic examples the methods of employment were examined, and the possibility of improvement of efficiencies by changes in methods was analyzed. This is the kind of operations research exploited by the United Kingdom and the United

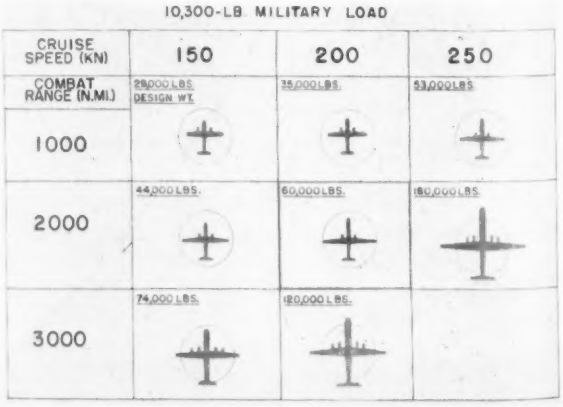


FIG. 4. Effect of cruise speed and range on airplane size.

States during World War II and is the kind of O.R. frequently pursued by many of our Government organizations. A considerable broadening of these areas of operations research is needed, however, for use in planning future air-borne weapon systems. A conceptual model, shown in Fig. 5, for a particular branch of warfare will help us visualize the main difference between this and the classic operations research. In classic O.R., emphasis is placed on examining the strategy and tactics of both sides to see if changes in our operations, using given weapons, might improve our results. Most wartime applications allowed little time for implementing extensive changes in weapons and equipment. In the kind of O.R. needed in the application discussed here, the total future components of both sides must be studied. We must examine all the possible weapons, equipment, vehicles, geopolitical situations, strategies, and tactics that might be available and employed by our side in this future period. We must examine similar factors for our possible enemies. These components must be analyzed theoretically in a future operational battle and the future results predicted.

The results can then be optimized for our side, thus generating the required functions and characteristics of the air-borne system to produce these results. The approach is simple in concept (see Fig. 6). The job, or the mission to be performed during the operational life of the airplane, is studied, defined, and measured, and this generates the requirement for the air-borne weapon system. This, in turn, leads to the selection of the best aircraft to serve as a vehicle in this system. Obviously, this kind of operations research is far more difficult than "classic" operations research. It requires the most comprehensive application of scientific methods and analyses. Sometimes this broad type of operations research is called "systems analysis," "systems planning," or "market research." Research groups have been active in similar work for several years, at RAND, Harvard, Cornell, and various Government military agencies. This is a fruitful and expanding area of research; it will continue to grow and find new uses as its value is recognized. What is being sought is the application of the scientific method, tools, and techniques of operations research to *improve the planner's bases for decision* and the probability that a newly conceived air-borne system will reach maturity and live out an efficient combat life.

Characteristics of the Analyses

So much for the reasons for such research and the general approach. Now, how does one go about such studies?

A request for a description of the methodology of this kind of O.R. is analogous to asking one to describe the process of seeking a cure for cancer. Although much progress has been made, a complete cure for cancer has not yet been found. No one can describe with certainty the exact processes that will lead to this achievement. In the case of this kind of O.R., the difficulty is increased because much of the experience to date has been gained on classified military projects that cannot be specifically discussed in this paper. However, something may be gained by first examining some of the common characteristics of such research and by following with an exposition of the general steps in a systems analysis. An attempt will be made to point out some of the tools and techniques thus far found useful. The guiding principles and characteristics common to many such analyses are listed below, not necessarily in order of importance:

(1) The scientific method must be used in conducting the analysis. The analysis must be truly objective in nature and cannot be biased, swayed, or slanted by preconceived notions or prejudices. Approach and point of view must be very broad, extending beyond the actual scope of the specific problem.

(2) A clear, concise statement or definition of what is thought to be the problem is important. It is imperative that the problem be thoroughly delimited. The amount and complexity of the analysis increase rapidly with expanding limits. Much time and effort will be saved by careful work at the beginning to ensure that the scope of the analysis excludes all factors and investigations that clearly will not contribute directly to achieving the answer required. As the study develops, frequent review of the delimited problem should be made to determine if the problem is still properly defined, if new factors have appeared, or if some previous factors may be rejected. Special attention must be paid to formulation of the basic assumptions, as these have a profound effect on validity of results.

(3) The probable operational job to be done in the future should generate the design characteristics of the air-borne weapon system. The investigation should constantly be guided by this concept of the future use of the system rather than its relation to current or interim operations. The analysis should examine a suitable future period that will allow full implementation of the systems resulting from the analysis.

(4) The weapon system concept must be employed. The aircraft shall be considered as only a component part of the air-borne system. The measure of effectiveness selected shall gage the capability of the weapon system to do the required job and shall not necessarily test the value of the aircraft as such. For example, from the designer's point of view an airplane may be good because it goes fast, is light in weight, has a long range, or carries a heavy load. The weapon systems analyst must be concerned solely with maximizing the efficiency of the entire weapon system to solve the stated problem.

(5) The analysis shall be quantitative wherever possible. Qualitative answers may be only one step removed from personal opinion. It must be borne in mind that the objective of such an analysis is to provide the executive with something more consistently accurate than he previously possessed.

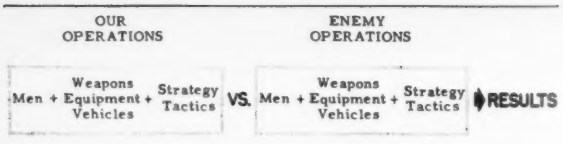


FIG. 5.

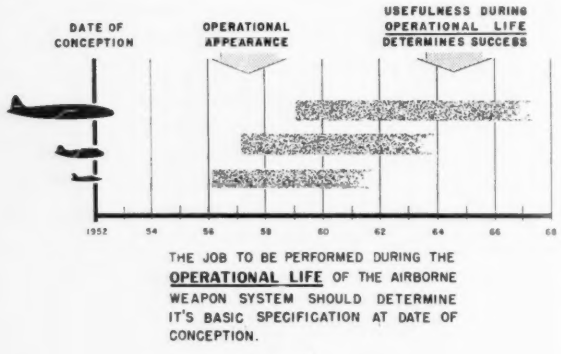


FIG. 6.

(6) The analysis should utilize the morphological approach, where necessary, to ensure that no useful solutions are overlooked.

(7) The analysis should be limited to determination of the important primary or fundamental parameters of the systems, such as range, speed, and pay load and their optimal values. Determination of secondary characteristics, such as swept wings or thin wings, tricycle gear or bicycle gear, are of dubious value. They are much more difficult to predict and are overshadowed in importance by the primary parameters. Secondary factors are amenable to determination by competition and the state of the art as the system develops and progresses.

(8) Time should not be wasted in obtaining excessive accuracies. The assumptions have established the limits of probable error. One is seeking solutions that are better than others by a large factor. Solutions offering only marginal advantages are probably subject to determination by factors outside the scope of the analysis.

(9) The study should be conducted by a small group of persons of the highest possible caliber. A diversity of specialized educational background and practical experience is important to bring true perspective and a large storehouse of scientific discipline. The group must be completely indoctrinated with the overall problem, imbued with the spirit of the team approach, and practiced in the art of group thinking. At least three broad fields of specialized ability should be present to reflect a complete perspective on the analysis. The group must contain the scientists and theorists, the engineers skilled in turning theory into hardware, and the users—people versed in the operations and tactical employment of weapon systems. Fig. 7 indicates the composition of such a group.

Typical Steps in Systems Analysis

The foregoing portrays some of the guiding concepts that characterize research to date into the methodology for aiding the long-range weapon systems planner. Next let us look at the five basic steps in a typical systems analysis to illustrate the application of these concepts. The first three of these usually proceed concurrently.

(1) *Statement of the Problem*—This step involves examination of the probable intentions, objectives, and national policy of the future enemy in the time period under consideration. It requires consideration of his probable economics and geopolitics and their possible variations during this future period, as well as his probable technological development and the weapons and equipment he may have during the projected period. It is necessary to define the probable theaters of operation and the locales in which the combats will occur. Also to be examined are the enemy's possible strategies in deployment and use of his available weapons.

It is obvious that some of the foregoing factors are not amenable to accurate determination, particularly where they involve enemy objectives and intentions. In such cases, it is often necessary to postulate a range of possible values of these factors and to carry them through the analysis to learn their effect on the results.

The value of the analysis is dependent almost entirely upon the realism and accuracy of the assumptions involved. Considerable time and utmost care should be devoted to the proper selection of the basic assumptions. This cannot be overemphasized.

By means of the foregoing considerations the problem has been thoroughly stated. There is now a good background against which to take the next step in the analysis.

(2) *Derivation of the Measure of Effectiveness*—A mathematical model must be developed stating the fundamental transaction taking place between these opposing systems. It contains terms that express the important variables in the air-borne weapon systems. This derivation of a measure of effectiveness is the most important single step and yet is probably the most difficult part of the analysis.

The purpose of the measure is to provide a yardstick by which one may determine the individual efficiencies of a whole series or spectrum of candidates for accomplishing the specified military mission. For example, Fig. 8 shows an oversimplified hypothetical mission in which system cost, probability of survival, and delivery accuracy vary with speed. Since each value of speed represents a different aircraft, a yardstick is needed to optimize the result for the overall problem to be solved. Fundamentally, the measure will contain terms reflecting the functional capabilities of the system and terms reflecting the cost of accomplishing the mission in this manner. These are sometimes expressed as output divided by input or vice versa. Essentially, the model

attempts to measure realistically "what you get for what you pay."

Once the measure-of-effectiveness model has been agreed on, a number of inferences that will be helpful in the rest of the analysis can be made. Some of the important factors in selection of the optimal system begin to emerge, the interrelation of these factors appears, the degree of accuracy required can be judged, and the sensitivity of the results to variations can be estimated. The model may also provide a basis for limiting the number of solutions which might have to be considered and examined in the remaining steps.

(3) *Study of Opposing Weapons, Equipment, and Tactics*—This step requires study of all available intelligence information, assessment of the state of the art in each pertinent technical field, and prediction of a range of probable future performance and operational characteristics of enemy weapons and equipment. Examination of the physical principles involved and the natural limitations and barriers to development often aids in such projections. These, incidentally, are also common to our own development problems.

At the same time, there should be a study of the developmental programs and a forecast of the air-borne weapons and equipment that could be made available operationally to the United States forces during the projected period. This is possible because major items of ordnance and equipment have development cycles similar in time scale to those of aircraft. If they are to be available operationally for the period under study, research and development planning work will precede them by a like period and therefore may be examined. The investigation may reveal apparent functional requirements for weapons not yet conceived or planned but considered technically possible. In this case, a hypothetical weapon may be postulated and carried through the analysis to determine its ultimate value.

Finally, it is necessary to study the probable tactics on both sides to determine the deployment and use of the available weapons in these future engagements. Game theory is often used to derive optimal strategies and thus to define the best or wisest courses of action for both opponents. By this means the upper limits of capability can be established.

It may be necessary to study in detail the effects of topography, hydrography, bathymetry, aerology, and other local environmental factors in the light of their influence upon operations. The study of the operational factors of opposing weapons and equipment can now be completed.

It is next necessary to synthesize a series of complete weapon systems.

(4) *Synthesis of Possible Solutions*—This step requires a study of the airplanes capable of serving as vehicles for the proposed weapon systems. The previous steps have provided a feeling for the type of performance required and have aided in narrowing the field of candidates. Suitable variations in the important airplane performance parameters are then chosen. An airplane parametric analysis is carried out in which performance and characteristics for a spectrum of airplanes are computed. A typical matrix is shown in Fig. 9. Complete weapon system families are then synthesized. Fig. 10 shows that these consist of weapons, equipment, crew, and vehicles, and represent a range of functional and performance capabilities of both the military load and the aircraft.

(5) *Evaluation, Analysis, and Conclusions*—Using the strategies and tactics previously determined, the various weapon systems are evaluated for the prescribed mission in opposition to the enemy's forces by application of the measure of effectiveness. (See Fig. 11.) The value of the measure is optimized for our side, and conclusions are reached as to the characteristics of the best systems. If the answers are sensitive to certain indeterminate factors, such as those under control of the enemy, they may be expressed in terms of a range of these factors. Alternative or compromise solutions are sometimes indicated. In such cases the penalties for compromise or nonoptimal selections are specified.

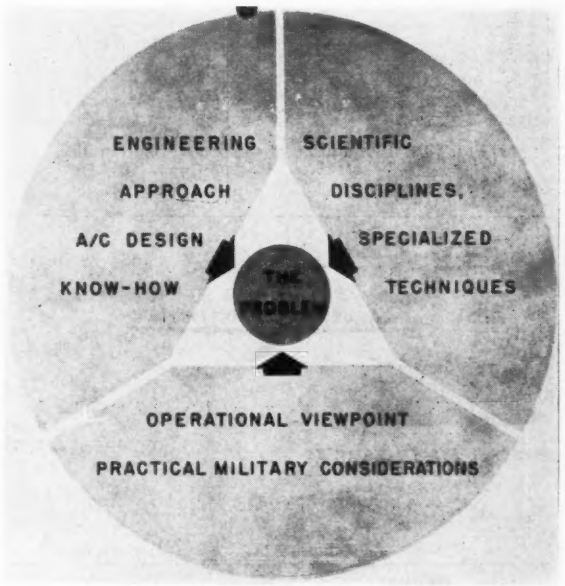
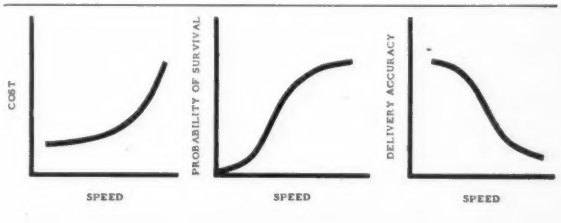


FIG. 7.



NOTE: CONSTANT RANGE AND MILITARY LOAD

FIG. 8.

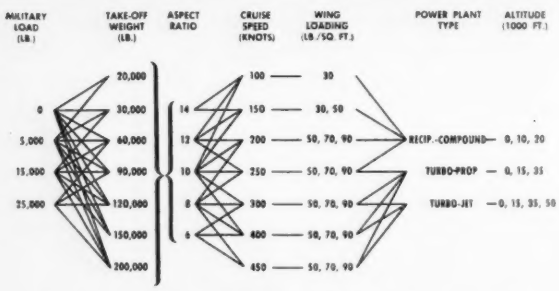


FIG. 9. Airplane parametric analysis, typical matrix.

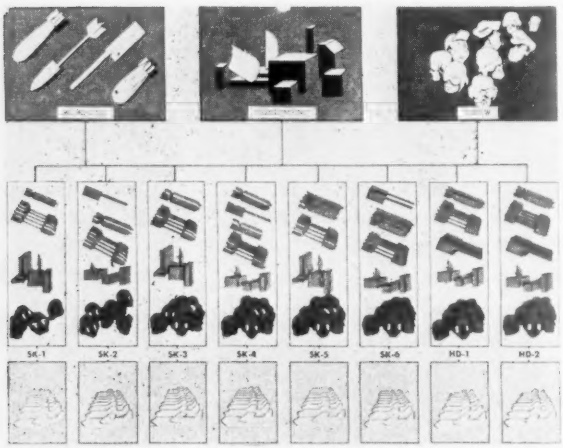


FIG. 10. Composition of weapon system families.

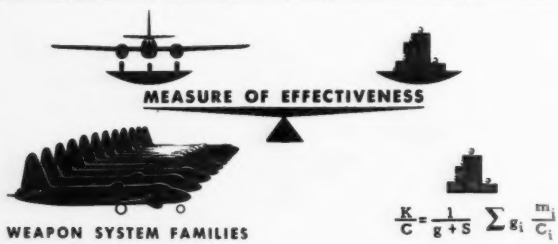


FIG. 11.

	OPTIMAL SYSTEM	A	B	C	D
CRUISE SPEED (K MI/HR)	235	300	235	235	300
COMBAT RANGE (N MI)	2600	2600	3500	2600	3500
MILITARY LOAD (LBS)	19,500	19,500	19,500	11,000	11,000
EFFICIENCY	1.00	.43	.77	.50	.11
GROSS WEIGHT (LBS) (APPROX)	88,000	360,000	140,000	36,000	360,000

FIG. 12.

VALUE OF RESULTS

By means of such a systems analysis the planner is provided with a comprehensive scientific study of his problem. The important or fundamental factors affecting the selection of the best air-borne systems have been determined. The planner can readily observe how the results are affected by variations in the assumptions used, and he can see the penalty for compromise. He has a framework into which may be inserted new assumptions or ideas as they occur in the future.

Fig. 12 shows a typical example of the penalties for errors in planning decisions for a new air-borne weapon system. Take the efficiency of the optimal system as 1.00. Then if, as in system A, the planner were to demand too high a cruise speed by only 65 knots, he would reduce the system efficiency to 0.43. In system B he has reduced the efficiency to 0.77 by demanding too large a combat radius; in system C he has reduced the efficiency to 0.50 by selection of too low a military load. If he were to miss all three parameters as shown in system D, an extremely inferior and costly weapon system would result.

Efficiency is a measure not only of cost but also of capability against the enemy; therefore, the value to the planner of the knowledge of such results before the airplane system is ever designed becomes obvious.

Although the value of such analyses is great, the cost is relatively small. Experience to date has shown that a typical systems analysis may be performed for a cost on the order of 2 to 10 per cent of the cost of a single production airplane. This appears to be a small premium to assure that we are getting the most power for the least number of dollars when creating a new air-borne weapon system to meet the enemy on equal or superior terms.

USE OF RESULTS

Some remarks are perhaps in order concerning the use of results of such an analysis. Frequently there is the feeling by the researcher that, once the results have been achieved, the job is finished. On the contrary, this may be only the beginning. The executive may not be standing by eagerly waiting to use the results. The operations researcher would do well to be aware of all of the several important steps in a complete transaction leading to proper use of results. These are believed to be the following:

(1) Recognize the problem.

(2) Analyze and get results.

(3) Make the solution(s) understandable to the executive.

(4) Develop agreement by the executive of validity of the results.

(5) Assist the executive in application of the results.

(6) Observe the degree of success of the application and turn the experience to new problems.

With respect to the third step, the researcher sometimes fails to realize that the customer may not be a scientist. He must have the results of complicated

analyses presented in such a way that he can grasp all of their implications. It may even be necessary for him to understand portions of the analysis. This is a matter of good report preparation and liaison. Even after understanding, he may not agree on the assumptions or the results, unless he accepts them solely on the basis of the scientist's reputation. If one is not in this happy position, it may be necessary to convince the planner of the soundness of the study and the answers. Problems may also arise in application of the results. Since there are always factors entering into the decision that cannot be accounted for in the analysis, the executive may need assistance in practical application of the results, particularly where compromises are required. Finally, the success of the entire process and application should be carefully monitored to obtain experience and data to reinvest in revision of the old analysis or to use in new problems.

Summary and Conclusions

The processes, methods, and techniques discussed in this paper are believed to be logical parts and extensions of the broad field of operations research. Although the references and examples given here are presented in terms of only military application, the methods appear to be adaptable as aids to decision in design and development of domestic aircraft, and in many other industrial fields as well.

In conclusion, it is believed that the extension and application of operations-research techniques to systems analysis can improve the basis for decisions on new air-borne weapon systems. Although only the surface has been scratched in this field and many things are yet to be learned, experience to date has provided reason for confidence that these methods will prove to be reliable and useful tools for the executive over the years. As experience and know-how increase, and sufficient groups of qualified personnel become available in both industry and the military, such analyses should become recognized as matters of good business procedure. It is to be hoped that, in the future, standard practice both in industry and in the Department of Defense will require that systems analyses be performed *in advance* of all basic planning decisions for design and production of future weapon systems.

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Design of an Airfoil Oscillator*

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Massachusetts Institute of Technology

ABSTRACT

This paper presents the development of an oscillator for imparting sinusoidal motions in pitch and translation to airfoils of various aspect ratios. Also included is the design of airfoil and fuselage models.

INTRODUCTION

EXPERIMENTAL RESEARCH has contributed its share toward the advancement of science in evaluating the theories that have appeared. Usually the results of experimental work appear as points plotted to compare theory with experiment, with little or no information on activities in regard to experimental design problems.

This paper presents the design of an airfoil oscillator, of which the base driving mechanism was reported in reference 1 under Contract NAw 5789 with the National Advisory Committee for Aeronautics.

DESCRIPTION OF OSCILLATOR MOVEMENT

A test arrangement of the oscillator is shown in Fig. 1. Energy from the drive motor is transmitted to the oscillator base (A). Through a gear arrangement the driving torque turns the drive wheels (B), four of which are on each side of the oscillator base. A driving crosshead is connected to two of the drive wheels with its ends off-center so that the crosshead moves up and down sinusoidally as the wheels turn. The off-center position is adjustable so that the amplitude of motion may be changed from 0 to 1 in. The motion is then transmitted to the vertical drive bars (C), which are constrained to vertical motion only by guide bearings on the upper and lower ends of these bars. Side forces on the vertical bars due to sliding friction of the horizontal crosshead are abated by oilite bearings held in place by leaf springs (D).

Attached to the top of the vertical drive bars are dural I-beams (E). The motion of these beams is transferred to the push-pull rods (F) and to the cam (G). From the cam the motion goes to the vertical links (H) and bayonet rods (I) and to the model (J).

When the push-pull rods oscillate in phase the cam translates up and down sinusoidally. The vertical links move in phase and the motion of the model is pure sinusoidal translation. If the push-pull rods operate 180 deg. out of phase, the cam pitches about its center point, which remains in the same horizontal plane. The rear vertical link is connected to the center of the cam and, thus, experiences no motion. The forward vertical link will have a vertical oscillatory motion as before but with a smaller amplitude. Since the rear mount is located on the mid-chord line—which is also the center of gravity—the resultant motion of the wing is pure sinusoidal pitch about its center of gravity. The angle of attack setscrew may be seen in Fig. 3 near the right edge and lower end of the forward vertical links. To change the angle of attack the cam is fixed in a horizontal position and the setscrew loosened, while the forward vertical links are moved upward to the proper position and locked in place by tightening the set screw.

DESIGN OF THE OSCILLATOR MECHANISM

With the exception of the cam (G) of Fig. 1, the design about which this paper is written covers everything from the driving crossheads on the drive wheels (B) up to and including the models. (Part of this paper is contained in reference 2.)

In Fig. 2 the leaf spring assembly preloads the mechanism in order to eliminate any free play that might develop and also to keep the driving force function as sinusoidal as possible. In the old oscillator of reference 1 the force was not exactly sinusoidal because of tension in the upper bands. The preload in the springs is established—and changed—by manipulating the adjustment screw.

The horizontal crossbeam is a dural I-beam with a moment of inertia of sufficient magnitude to restrict the vertical deflection of the beam to less than 0.002 in. under the maximum design load.

In designing the push-pull rods, the same vertical deflection restriction was enforced, and the rods were checked for column stiffness. For vertical adjustments the push-pull rod has right-hand threads in the upper end, while the lower end has left-hand threads. The lower fitting on the push-pull rod is easily moved to new positions on the horizontal crossbeam in order to test wings of different aspect ratio and sweepback angles.

Above the wind-tunnel floor the oscillator cam mechanism will be mounted, as shown in Fig. 3. For semispan wings only one camstand assembly is used, along with a root support end plate and fairing. Four vertical links connect the cam with the bayonet rods. A vertical link is attached to each side of the cam so that the loading on the cam is symmetrical, and thus any tendency for the cam to twist is eliminated. One

* This paper is based on the experimental part of a theoretical-experimental thesis submitted to Massachusetts Institute of Technology in partial fulfillment of the requirements for the degree of Master of Science in Aeronautical Engineering. The work was conducted on USAF Contract AF 33(038)-11668.

† Now Aeronautical Engineer, Bureau of Aeronautics, Department of the Navy.

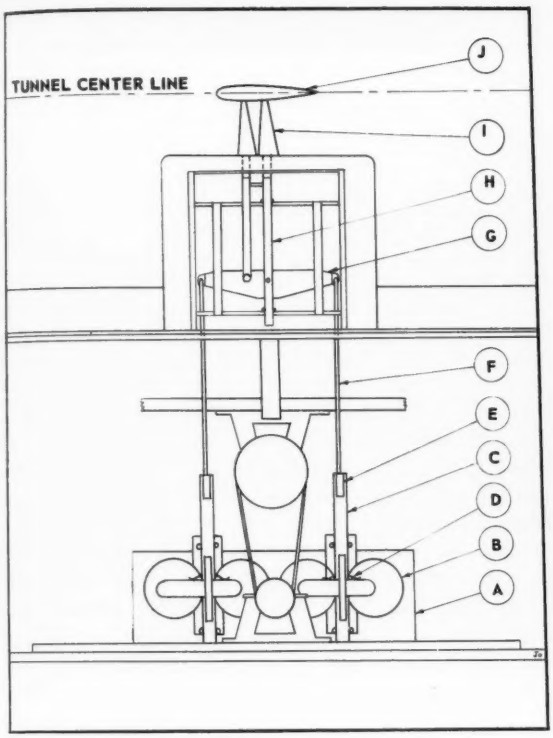

FIG. 1. Airfoil oscillator.

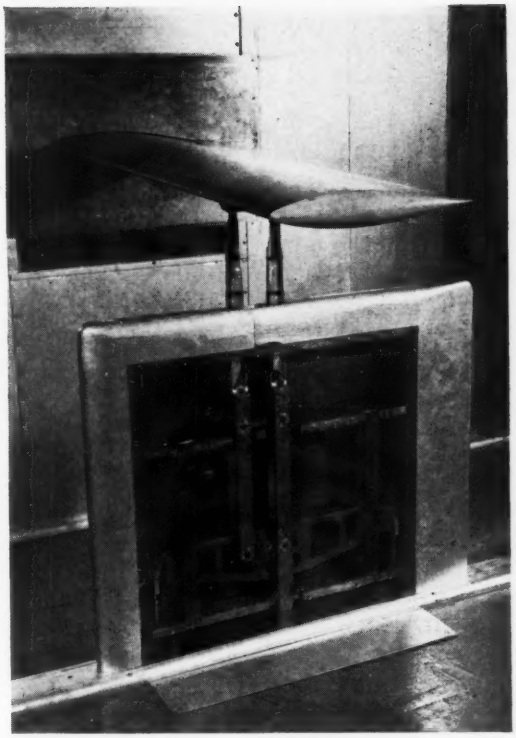

FIG. 3. Airfoil oscillator semispan configuration.

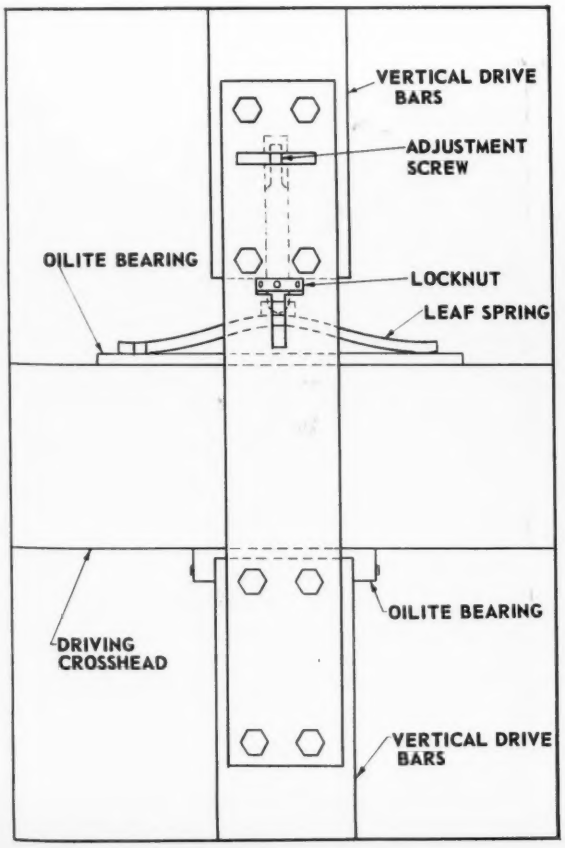

FIG. 2. Leaf spring assembly.

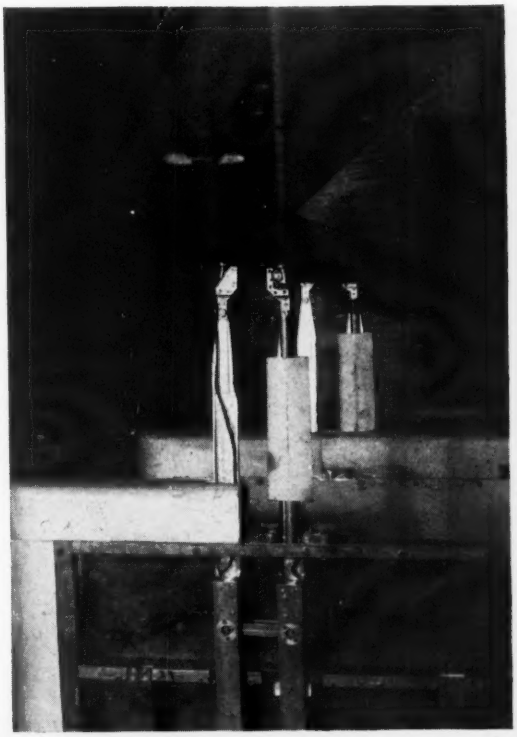

FIG. 4. Airfoil oscillator swept-wing configuration.

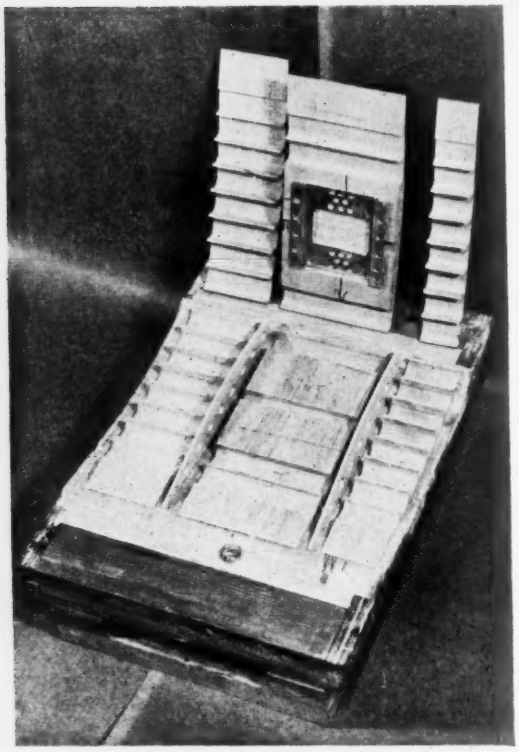

FIG. 5. Wing internal construction.

of the vertical links in the center of the cam extends downward to the lower guide bearing, which constrains the link to vertical motion only. The horizontal link between the vertical links is a lateral support for the forward vertical links, and it completes the four-bar linkage to control their motion.

In between the upper ends of the vertical links are mounted the bayonet rods shown in Fig. 4. The basic bar is machined into an I-beam shape. The flanges are straight at the lower end for the purpose of operating in the upper guide bearing, which constrains the bayonet rod to vertical motion only. From the guide bearing up, the flanges taper to the thickness of the web. The upper portion of the web is machined thicker than the lower portion to provide side bending stiffness as the flanges taper below a safe width. A fairing is bonded to the bayonet rod to reduce turbulence. Wires from strain gages are taped to the web of the bayonet rod.

On the top of the bayonet rod is mounted the strain gage cantilever beam mount seen in Fig. 4. The mount is machined from one piece of dural, the lower part being drilled to match the upper end of the bayonet rod. The free end of the cantilever beam is drilled to receive a pin that is threaded on one end for mounting a $^1/_8$-in. steel ball. The pin and cantilever beam are locked together by a taper pin located on the neutral axis of the cantilever beam. The center of the steel ball is located at the intersection of the vertical center-

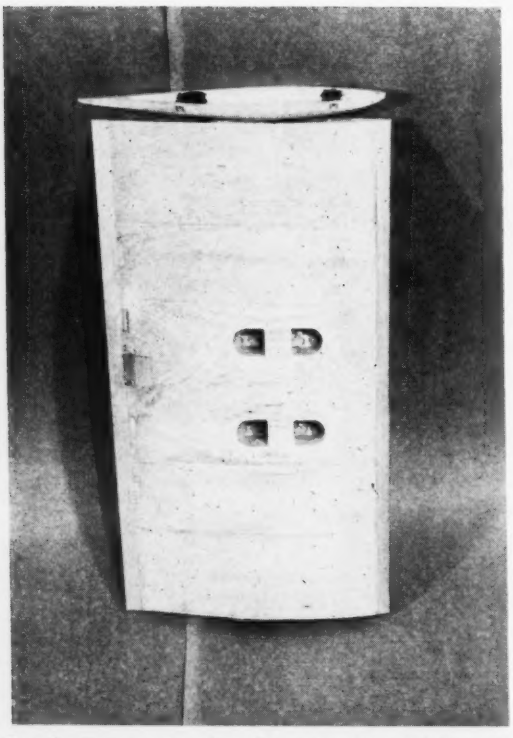

FIG. 6. Rectangular wing of aspect ratio = 2 before skin is mounted and with one interchangeable wing tip resting on top. (Apparent taper is due to angle at which picture was made.)

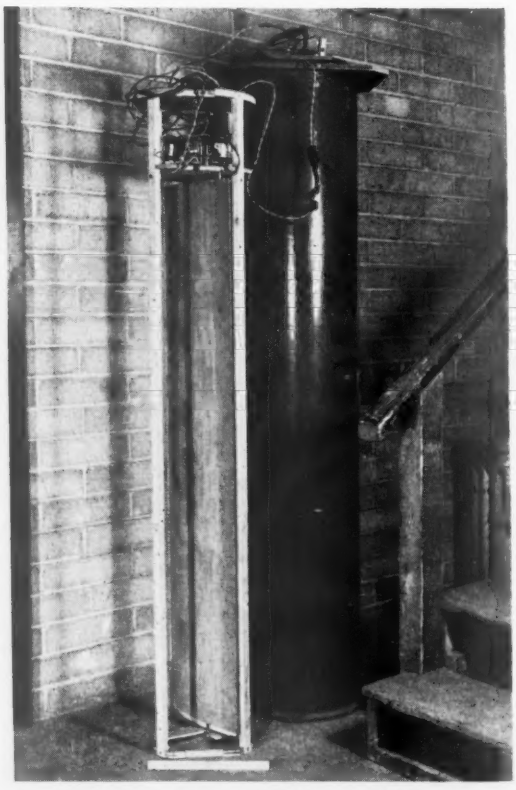

FIG. 7. Vacuum-tank bifilar pendulum.

line of the bayonet rod and the chord line of the wing. Strain gages are mounted on the upper and lower surfaces of the cantilever beam.

The wing attachment bearing assembly is a socket receptacle for the steel ball that rests between two formed oilite bearings. Two plugs screw into the socket above the upper bearing. The lower plug eliminates free play between ball and bearings, while the upper plug locks the lower plug. Four holes in the top of the socket match corresponding holes in the wing mounting plate.

Wing and Fuselage Design

In order to simplify the construction of the wings a "standard section," shown in Fig. 5, was designed and produced. The sections are rectangular with a length equal to the chord of the wing and having a spanwise width of $4^1/_8$ in., the $^1/_8$-in. being a balsa rib. The 4-in. part is made of two balsa blocks equal to half the wing thickness and bonded together along the chord line. Before bonding, the blocks are slotted so that spars of $^1/_8$-in. thickness and 1-in. spacing run in a spanwise direction. The depth of the slots is such that a $^1/_8$-in. balsa skin remains after the airfoil is sanded to shape.

At the support points the standard section was replaced by a mounting section.

A magnesium skin was applied to the wings of aspect ratio 4, 6, and 10, whereas the aspect ratio 2 and 1 wings were covered with rice paper. Since the widest magnesium sheet available was 1 ft. wide, the leading edge was removed, the skin bent around, and a balsa leading edge added.

In Fig. 6 a partly finished wing of aspect ratio 2 is shown with its balsa leading edge, sycamore trailing edge, balance weights, and one interchangeable wing tip.

For the rectangular wings the moment of inertia was measured by use of the vacuum-tank bifilar pendulum arrangement shown in Fig. 7. The disc at the upper wing tip is movable to accommodate wings of different aspect ratio. The wing was held in the maximum amplitude position by a solenoid. When the wing was released, a small mirror on the wing tip passed under a light and reflected it to a photoelectric tube, the output of which was amplified and recorded on an oscillograph.

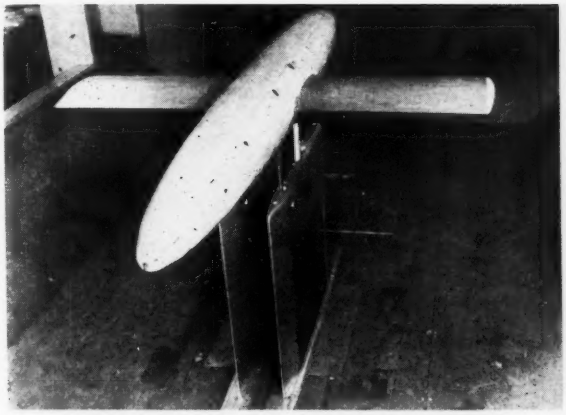

Fig. 8. Fuselage-wing configuration. Fuselage length: 75 in.; fineness ratio: 10; straight wing of aspect ratio = 4.

The fuselage was of semimonocoque construction, with a length of 75 in. and a fineness ratio of 10. The front bayonet rods were attached to the center of the cam, while the rear ones extended directly to the rear end of the cam. A test arrangement with a straight wing of aspect ratio 4 is shown in Fig. 8.

Conclusion

In general, the system as explained was very satisfactory. Extreme care had to be given to alignment of the oscillator, since a minute misalignment within the linkage showed up as a measured force of considerable magnitude.

Another critical adjustment was in the ball and socket fittings previously described. Considerable time was required to get the bearings to the correct degree of tightness. If the bearings were too tight, friction induced a bending moment on the end of the cantilever during pitching motion, whereas, if they were too loose, the motion in pitch and translation was neither sinusoidal nor smooth.

For the full-span models it was necessary for the four sockets to be in the same plane—by no means an easy task.

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[1] Halfman, R. L., *Report on Systematic Tests with An Airfoil Oscillator (Phase 4)*, M.I.T. Flutter Research Laboratory, February 1, 1948.

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Human Factors in Jet-Transport Design

FRANK C. HALE*
Douglas Aircraft Company, Inc.

IT APPEARS ADVISABLE, when discussing human factors in a jet-transport study program, to include an outline of some of the reasons why a human engineering group may exist within the Engineering Division of an aircraft manufacturer and of what specialties that group would be comprised. The Human Engineering Group at Douglas Aircraft Company's Santa Monica Plant is apparently the only such full-time group in existence within the industry. Consequently, you might be interested in what this group has to contribute to the engineering design of an aircraft and to what extent it is fulfilling its purpose.

While attempting to approach the subject of human engineering and human factors without being academic and pedantic, I talked to one of our engineers. He suggested, and I believe that these were his exact words, "Why don't you just tell the truth?" Since this is an approach seldom attempted by writers, it seemed a bit radical. After some association with an engineering division, I can appreciate the fact that such a comment is based on more than cynicism. There has already been too much written and said in either glorification or vilification of the human engineer. From the design engineer's standpoint there is a good reason for the existence of human engineering groups, unfortunately, often quite different from the human engineer's own estimate of himself.

It is the common concept, among those who do human factorial work, that the design engineer, in striving for higher altitudes and higher speed aircraft, developed mechanical and technical advances that produced aircraft in which the human tolerance was being reached or surpassed. When this came about, the human engineer rode up on his white rat (Wistar strain) and, championing the cause of the common man, did battle with the design engineer.

The design engineer has a slightly different concept of this struggle. It is his contention that when he realized that he was building aircraft that taxed the limitations of the human, he turned to those specialists—physiologists and psychologists—whom he assumed could tell him what he must do to alleviate these conditions. He admits, in all fairness, that they probably did, but he could not understand a single word of it. There was only one course open. Human engineering personnel were hired, with the express duties of translating the words of the specialists into language that the design engineer could understand and use.

Presented at the Human Problems of Flight Session, National Summer Meeting, IAS, Los Angeles, June 21–24, 1954.

* Research Engineer, Human Engineering Group, Interiors Design Section.

Somewhere between these two concepts lies the inevitable compromise that is probably the truth. It is true that, as the need arose to extract the last fraction of power, without unnecessary penalty to the design, so that the plane might fly farther, faster, and higher, aerodynamics took over as the deciding factor in the outer configuration. This desire for the ultimate in streamlining limited further and further the availabilty of space within the fuselage. Finally, a few years ago, a plane came off a production line with what were undoubtedly excellent aerodynamic characteristics. Only one minor point had been ignored. There just was not room enough inside to squeeze in the crew. Abashed by the cost of the conversion necessary to permit the introduction of a crew, the Air Force decided that henceforth all future designs would be checked as to their suitability for human utility by human factors teams from the Air Research and Development Command. This means, in theory, that for military aircraft the human factors conscience is supplied with the contract. In practice it has not been the case since the unavailability of properly trained personnel to staff these crews has seriously hampered the program. The solution of most human factors problems in engineering design is today the responsibility of the manufacturer, in the fields of both military and commercial aircraft.

Commercial aircraft manufacturers have long been cognizant of the advantages of such human factors as comfort and safety when producing a competitive product. Basically, what we refer to today as human factors are simply amplifications of these two factors as they apply to the occupants of higher and faster aircraft. No manufacturer would expect to produce a design that did not display the latest technical and scientific advances in aerodynamic thinking or communications; therefore, he should also incorporate in this design the best of current human factors thought.

The question arises as to whether the necessary human factors evaluations can be best accomplished through the use of outside consulting agencies or through the employment of a permanent engineering division. There is little doubt that, specialist for specialist, a higher type of consultant can be obtained from outside agencies. However, there is the problem of economics involved in the permanent employment of these individuals. Whether permanent employees can offset this disadvantage through continuity of effort is a moot question. In the past, most aircraft manufacturers have relied upon certain design philosophies to differentiate their aircraft designs from those of their competitors. In the commercial market, these design philosophies have become stock in trade and their continu-

ance a necessity for the manufacturer. The difficulties of imparting these philosophies to outside consultants, employed for only short periods of time and without intimate contact with the entire plant of the manufacturer, are evident.

At the Douglas Aircraft Company's Santa Monica Plant, where the production of commercial aircraft is centered, a combination of both means is employed to arrive at human factors design answers. A group has been established within the Interiors Design Section which serves to maintain a continuity of effort and philosophy. When problems arise which appear to be beyond the scope of this group and which do not appear to warrant the addition of permanent personnel for their solution, the group serves as a nucleus where information is absorbed from specialists either from other Douglas plants or from consulting agencies and guided into channels of greatest utility to the engineering designer. The greatest value of the group appears to be in this capacity of interpretation—on the one side, the gathering of information from the various human factors specialists, on the other side, the translation and transmission of this same information into the language and form usable by the engineer.

An outline of the physical make-up of this group may be of interest (Fig. 1). It should be pointed out that this group has evolved through no fixed course or plan but, somewhat like Topsy, has just grown. As problems arose which appeared to warrant the assignment of permanent personnel, either new group members were employed or employees with the necessary educational and experience qualifications were assigned.

The fields of effort are self-explanatory on the chart shown. In the organizational setup of the Engineering Division, this group functions under the supervision of the Chief Interiors Design Engineer, since the responsibility to design for all matters within the fuselage is delegated to this section—except, of course, such matters as would specifically and obviously fall to other sections, as Air Conditioning, Equipment, Power Plant, etc. In all matters reflecting the human reaction, the Human Engineering Group serves in an advisory capacity to these other sections. This is particularly true when a specific model is in the preliminary design stage. As an illustrative example, I shall outline some of the studies that have been carried out at the request of the Jet-Transport Study Program Section and the Preliminary Design Section relative to Human Factors as they might affect the design criteria of a commercial jet transport.

Two major studies were carried out in the cockpit area. One dealing with the location of crew and instrumentation was based upon a comprehensive study of crew duties under varying flight conditions, including emergency. Upon the basis of this study it was possible to advise on the optimum location of instrumentation to provide the maximum utilization of personnel, at the same time eliminating unnecessary duplication of

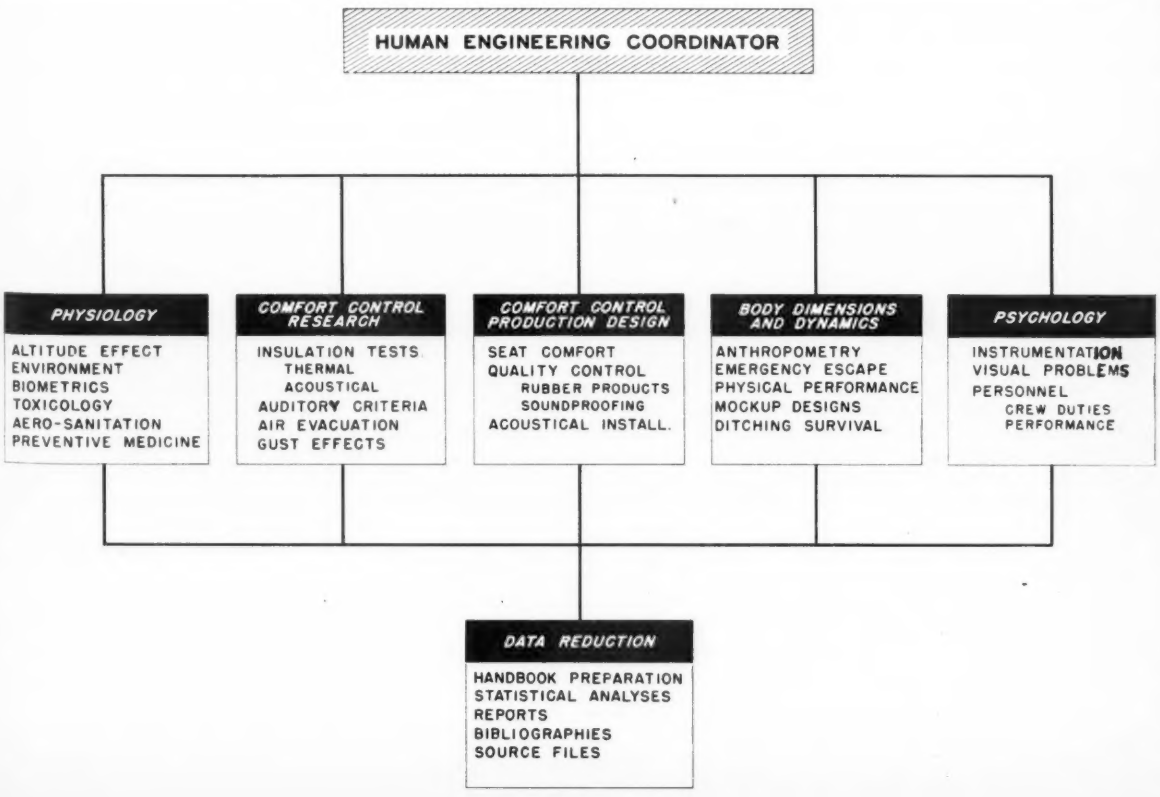


FIG. 1.

effort and instruments. The second of these studies dealt with the complete redesign of the pilot's seat, reducing the mechanical complications to a minimum and, at the same time, increasing the comfort and maneuverability of the seat as a means of delaying the pilot's fatigue and obtaining his maximum efficiency.

Several studies have dealt with the passenger cabin. One of the more important of these related to passenger seating. Here, as in the pilot seat, complete redesign was resorted to. The result is a seat capable of fitting a greater percentile of the population with a higher level of comfort than formerly. Such additional fields were explored as the optimum design of leg and foot rests, quality control of manufactured parts necessary for maintenance of maximum comfort, determination of the point beyond which quality control does not give reasonable return, optimum aisle clearance, and development of a new headrest.

In connection with the passenger seat, two other studies were carried on. One comprised a statistical evaluation of seat width in relation to the percentile of population fitted. Based on this statistical approach, a mathematical formulation was evolved for a minimum-weight fuselage cross-section perimeter, as related to seat width and population fitted.

A study was carried on to determine the optimum size and location of emergency exits, as related to escape, in conformity with similar C.A.A. studies.

Passenger reactions to varying window dimensions were also tested in order to determine the optimum window size from a passenger comfort and usage standpoint.

Two projects relative to passengers are currently underway. One is concerned with the utilization of direct and indirect lighting under conditions of high-altitude luminosity, with regard to both passenger cabin and cockpit lighting. Concurrently with this study, the effects of high-altitude luminosity on fabric colors and textures are being explored on behalf of the Industrial Design Group. The second project delves into aerosanitation, including both the problems of an integral water supply system and an integral wastes disposal system. In this connection, a study is being carried on among current air carriers to determine accurately the amounts of wastes produced, as related to flight time, food and liquor consumption, and diurnal variations.

Several studies have been carried out which affect the aircraft as a whole. Chief among these are the acoustical studies. This problem has been approached by a variety of means: theoretical considerations based on information obtained from the power-plant manufacturers; correlation of expected conditions to known conditions in existing aircraft, including jet aircraft in the same speed range; and use of a full-scale acoustical mock-up, simulating the various flight conditions relative to noise production.

Studies have also been made relative to the physiologic state of the passengers following decompressions of varying intensities, ranging from the simple loss of a cabin window to the largest hole sustainable by the aircraft while still maintaining operation and maneuverability.

Based upon the results of these studies of decompressions, therapeutic and emergency oxygen supplies and equipment requirements have been determined. Upon these same results operational characteristics of the aircraft were assessed from a human factors standpoint, and various criteria were established—such as the required rates of descent under varying emergency conditions—which were employed by the S.A.E. A-9 Subcommittee in the preparation of S.A.E. Aeronautical Information Report No. 33, currently in press. Details of these methods of evaluation will be published shortly.

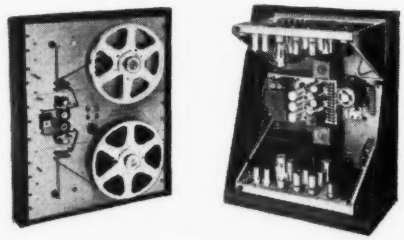
An evaluation of the air conditioning system from a health and comfort standpoint has been made in relation to such items as contamination by toxic materials and temperature and humidity control.

Many of these studies have been completed, some are still in progress, and many will never be completed, since it must be emphasized that human factors studies are continuing efforts in common with most other fields of endeavor in the aeronautical sciences.

There is little that I can say regarding an evaluation of the work done by this group. It seems obvious that human engineering has many facets and much to offer the design engineer. All the design engineers with whom I have worked have been anxious to obtain such information and quick to apply it to design criteria. With such acceptance there can be little doubt that, when a commercial jet transport is produced, it will reflect much of the work being done through human engineering and will be efficiently designed for the transport of man.

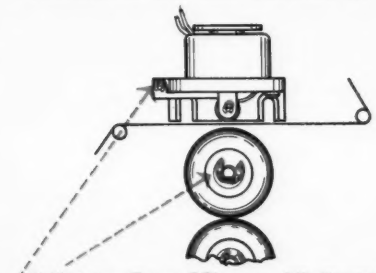
30 Waldes Truarc Rings Save Space and Time... Simplify Assembly and Disassembly

Potter's New Digital Magnetic Tape Handler



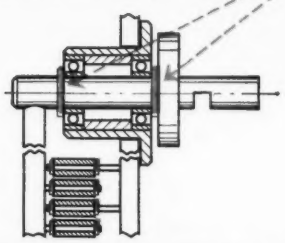
■ Prime requirements: fast starts, fast stops, fast tape speeds, great accuracy. Using Truarc rings, this new model starts and stops the tape within 5 milliseconds, has tape speeds up to 60 inches per second.

Solenoid Mount and Capstan Assembly



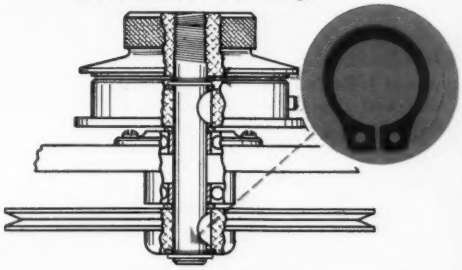
■ Miniature Truarc E-Rings on .040 diameter shaft and on continuously running capstans eliminate projecting bolts and screws. Rings permit rapid assembly and disassembly, fast replacement of worn rubber capstans.

Tension Shaft Assembly



■ Truarc E-Rings snap quickly into place, act as shoulders for the ball bearings with a minimum of friction. Additional Truarc Rings are used as spacers on shafts, can be located accurately to extremely close tolerances.

Reel Shaft Assembly



■ Truarc Standard Rings (Series 5100) hold the reel shaft assembly firmly in place and permit the use of quick-lock hubs so that the reel tapes can be changed in seconds as they are finished.

Potter Instrument Company, Inc., of Great Neck, L. I., uses 30 Waldes Truarc Retaining Rings in their new Model 902 High Speed Digital Magnetic Tape Handler. In addition to solving a variety of fastening problems, Truarc Rings facilitate the rapid acceleration and fast stopping needed in these machines.

Wherever you use machined shoulders, bolts, snap rings, cotter pins, there's a Waldes Truarc Retaining Ring designed to do a better, more economical job. Truarc Rings are precision engineered, quick and easy to assemble and disassemble. They save time and increase operating efficiency.

Find out what Waldes Truarc Retaining Rings can do for you, toward saving costs and improving your product. Send your blueprints to Waldes Truarc Engineers for individual attention without obligation.

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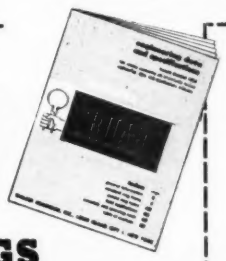

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Company .....

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IAS News

(*Continued from page 37*)

Carl B. Meade (TM), Assistant Foreman Technical, Sperry Farragot Corporation, Subsidiary of The Sperry Corporation. Formerly, Inspection Methods Engineer, Sperry Farragot.

James L. Murray (AF), Engineering Representative, The Garrett Corporation. Formerly, Lieutenant Colonel, USAF, Chief, Engineering Division, Headquarters, USAFE.

Norval D. Peterson (TM), now Junior Engineer, Chance Vought Aircraft, Incorporated.

Ronald F. Probstein (TM), with Division of Engineering, Brown University. Formerly, Assistant Professor of Aeronautical Engineering, Princeton University.

Edward H. Raiguel (M), Director—Aircraft Engineering, Overhaul and Supply Depot, American Airlines, Inc., Tulsa, Okla. Formerly, Development Engineer—Instruments and Electrical, American Airlines, Flushing, N.Y.

C. T. (Tom) Reid (AF), Executive Staff, Northrop Aeronautical Institute. Formerly, Director, Employee Education and Training, Grand Central Airport Company.

Raymond J. Reilly, Jr. (TM), Engineer, Overhaul and Supply Depot, American Airlines, Inc., Tulsa, Okla. Formerly, Junior Engineer "B," Engineering Service Department, Boeing Airplane Company.

C. T. Ryan (M), Assistant to Chief Designer, Vard, Inc. Formerly, Design Group Leader, Canadair Limited.

Kelly G. Smith (M), Chief Tool Engineer, Chance Vought Aircraft, Incorporated. Formerly, Chief Project Engineer, Canadair Limited.

David D. Thomas (M), Deputy Director, Office of Federal Airways, CAA. Formerly, Acting Chief, Planning Staff, CAA.

Willys E. Thomas (M), Executive Vice-President, Magnaflux Corporation. Formerly, Vice-President—Sales, Magnaflux.

Dr. George F. Wislicenus (M), with Ordnance Research Laboratory, Garfield Thomas Water Tunnel, The Pennsylvania State University. Formerly, Professor and Chairman, Mechanical Engineering Department, The Johns Hopkins University.

Second Lieutenant Philip Zove, USAF (TM), Aeronautical Engineer, Climatics Unit, Directorate of Flight and All Weather Testing, Wright-Patterson AFB, Ohio. Formerly, Graduate Student and Recipient (June, 1954), Master's Degree in Aeronautical Engineering, New York University.

Corporate Member News

• **Aeroquip Corporation. . .**Two new types of flexible hose lines designed for aircraft use have been brought out by the corporation. One of these is the new 601 jet-engine hose that is smaller, lighter, and more heat-resistant and has a greater flexibility than the standard Aeroquip type now in use. The other new hose is the 617, which was developed to fill a USN request for a lighter and less cumbersome hose for air-frame applications, as, for example, between fuel tanks or between a fuel tank and the engine.

• **Air Associates, Inc. . . .**A new ten-channel VHF transmitter, designated the Aerotron Model 200, is being distributed exclusively by Air Associates. This transmitter can be installed in any standard $2^1/_4$-in. mounting and weighs 8 oz.

• **American Airlines, Inc. . . .** A recent release states that American has developed a new type of "Go-Now Pay-Later" credit plan for world-wide travel. According to the company, this plan requires no down payment, 12 months to 2 years to pay, and covers everything from air fares to ground transportation costs at the point of destination. The plan was developed in cooperation with a community bank in each city.

• **American Bosch Arma Corporation. . .** Effective last July 21, the Arma Corporation merged into its parent corporation, American Bosch Corporation. Under its new trade style the corporation now has two divisions: American Bosch Division at Springfield, Mass., and Arma Division at Garden City, L.I., N.Y. The officers of American Bosch Arma Corporation are as follows: Chairman of the Board, Donald P. Hess; Vice-President—Finance, David F. Devine; Vice-President—Operations, Clifford A. Sharpe; Treasurer, Frank I. Bertsch; and Secretary, James M. Carroll. Other officers of American Bosch Corporation and Arma Corporation retain similar positions with the respective American Bosch and Arma divisions.

• **Beech Aircraft Corporation. . .**Two ground power units—the C-26 and the MD-3 portable generators—are now being built by Beech under a USAF contract. Beech has been delivering the C-26 to the Air Force since November of 1952. The Beech-designed MD-3 is a more powerful modification of the C-26. Both of these units will be used to start the engines of jet-powered planes and to supply an independent source of power for operating the electronics systems of military planes while they are on the ground. . . .It was estimated last summer that the new Beechcraft Super 18 would be delivered at the rate of eight units a month by this time. Powered by two Pratt & Whitney R-985 AN 14B engines, the Super 18 has a maximum speed of 234 m.p.h., a cruising speed of 215 m.p.h., and a range of 1,455 miles. Its gross weight is 9,300 lbs.

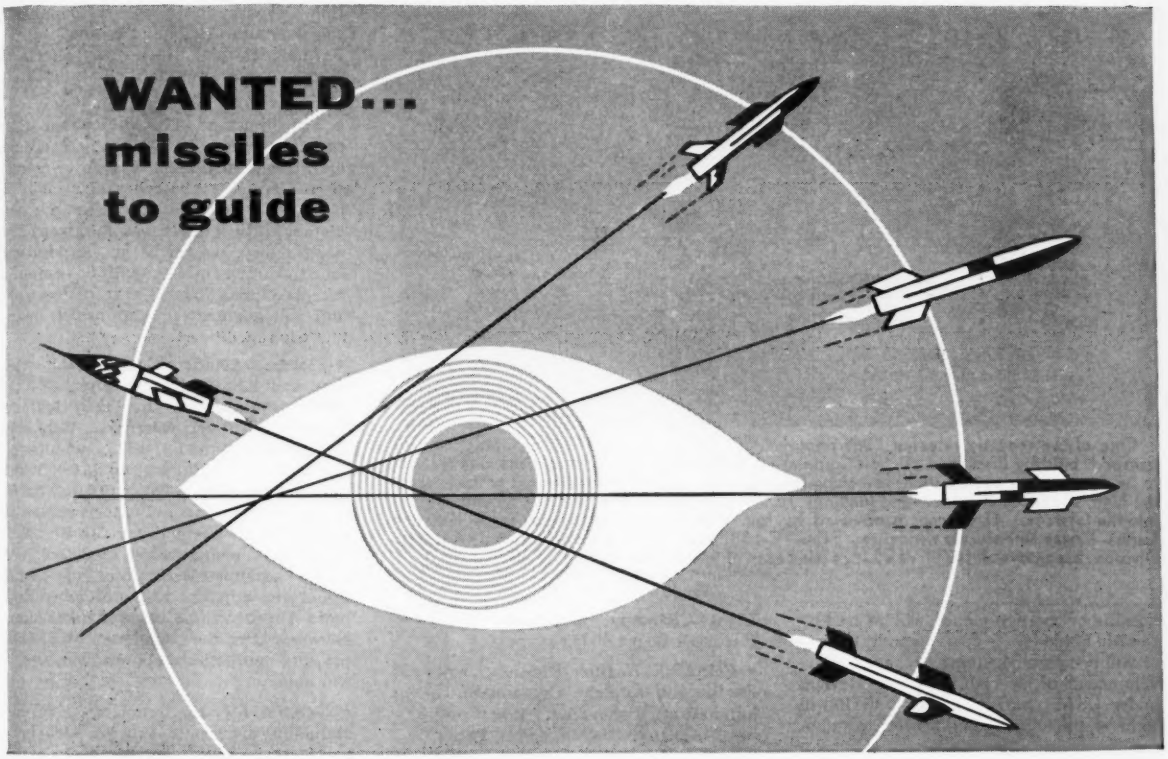
• **Bell Aircraft Corporation. . .**It was reported in July that the speed attained on December 12 at Edwards AFB, Calif., by Major Charles Yeager, USAF, flying the Bell X-1A rocket-powered research plane, has been officially recorded as 1,650 m.p.h. . . .A 14-page booklet entitled "The Bell Rotor System" has been published by the company's Helicopter Division. The publication describes with illustrations various features of this helicopter rotor system. A complete technical discussion of the Bell Rotor System, Bell Report Number 30-929-123, is available gratis on request.

• **Bendix Aviation Corporation. . .**A recent company announcement states that fuel-air combustion starters developed by Eclipse-Pioneer Division have qualified according to USAF specifications.

• **Boeing Airplane Company. . .**It has been revealed that two Pratt & Whitney J57 turbojets have been installed in each of two Boeing B-47B Stratojet bombers. The specially equipped medium bombers are being used as part of the Boeing B-52 Stratofortress test program. In addition to the engine installations, the modified B-47's have also been equipped with numerous B-52 parts, including B-52 nacelles that were reworked from double- to single-pod design. One of the J57-powered Stratojets is now in service with the Flight and All Weather Testing and Evaluation Branch of Wright Air Development Center, Wright-Patterson AFB, Ohio; the other modified Stratojet is at Boeing's Wichita Division. . . .The first production model of the B-52A Stratofortress made its initial flight at Seattle on August 5. This bomber, which weighs more than 350,000 lbs., is powered by eight Pratt & Whitney J57 turbojet engines. The overall length of the B-52A is 156 ft.; its sweptback wings measure 185 ft. from tip to tip; and its sweptback tail, which may be folded to a horizontal position for hangar clearance, is 48 ft. in height. . . . The Stratotanker-Stratoliner, Boeing's $15,000,000 private investment, is now undergoing an extensive flight-test program at the company's new flight-test center at Boeing Field, Seattle. This jet-transport prototype made its maiden flight on July 15, taking off from the Renton, Wash., Municipal Airport at a weight of 110,000 lbs. and landing 1 hour and 24 min. later at Boeing Field. This ship is powered by four Pratt & Whitney JT3-L turbojet engines, each developing more than 10,000 lbs. of thrust. The aircraft has a normal cruising speed in the 550-m.p.h. range, a wing span of 130 ft., and a length of 128 ft. Its gross weight is 190,000 lbs.

• **The Cessna Aircraft Company. . .**The first production delivery of Cessna's Model 310 twin-engined small executive transport was made about mid-July. This 5-place aircraft, which cruises at 205 m.p.h., is powered by two Continental 240-hp. engines.

• **Convair Division of General Dynamics Corporation. . .**The first of a number of C-131B's, ordered by the Air Force for testing electronic equipment, will be delivered late this year. These aircraft, slightly larger than the C-131A Samaritan



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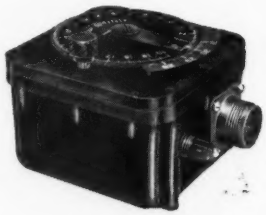
for the remote electrical transmission of data such as true airspeed, indicated airspeed, absolute pressure, log absolute pressure, differential pressure, log differential pressure, altitude and Mach number.



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One of the recently released "first photographs" of the new YC-130 turboprop military transport, built by Lockheed Aircraft Corporation, is shown here. Among the design features to be noted in this aircraft are its low-slung fuselage with a floor the same height as truck beds; the high, upswept tail for rear-end loading; and the tandem landing gear that rises straight up into the fuselage. The aircraft is powered by four Allison T-56 turboprop engines turning Curtiss-Wright Turbolectric propellers. The YC-130, to be produced at Lockheed's Georgia Division, has an overall length of 95 ft., a wing span of 132 ft., and a height of 38 ft.

hospital evacuation planes, will be used by the Air Force for its own research projects or will be assigned to firms engaged in development of special electronic devices under USAF contract. The C-131B will come equipped with fittings to accommodate passenger seats so that the plane can be quickly converted to transport service. Provisions will also be included to permit easy installation of a radome beneath the fuselage. The C-131B has a take-off gross weight of 47,000 lbs. and an empty weight of 29,000 lbs. Its top speed is 265 knots, and its cruising speed is 240 knots. As a transport, the aircraft can carry 48 passengers and a crew of two. The C-131B is powered by two Pratt & Whitney R-2800-99W engines turning three-bladed, fully feathering, and reversible Hamilton Standard propellers. . . . A new $250,000 test facility for use in one of the USAF's guided-missile programs is now under construction at Point Loma, Calif. This facility, which will consist of a steel tower, two sheds, and a horizontal testing fixture for vibration and air-pressure tests, is designed not for firing missiles but for testing components and systems. . .. A $100,000, 5,200-sq.ft. electronic computer research building is now under construction at the San Diego Plant One. Located adjacent to Convair's engineering building, this new two-story concrete structure is scheduled for completion by January 1, 1955.

• **Douglas Aircraft Company, Inc. . . .** The five-hundredth airplane of the DC-6/7 series of transports was made ready for flight on July 22. This particular airplane was a DC-6B to be delivered to Western Air Lines, Inc. All of the DC-6's—the first one was delivered in 1946—are powered with Pratt & Whitney R2800 engines. The DC-7's, which first entered air-line service in 1953, are powered by Wright turbocompound engines. Both the DC-6B and DC-7 commercial transports, along with their military versions, are rolling off the same production line.

• **Eastern Air Lines, Inc. . . .** McGregor Smith, Chairman, Florida Power and Light Company, has been elected to Eastern's Board of Directors.

• **Fairchild Engine Division, Fairchild Engine and Airplane Corporation. . .** Two hundred acres of industry-zoned property have been purchased at Deer Park, L.I., N.Y., for the Engine Division's new main factory. The new plant, to be erected within 12 to 18 months after plans are approved, will have administrative-engineering offices and an advanced turbine-engine test laboratory. The main plant that the Fairchild Engine Division has been occupying at Farmingdale, L.I., N.Y., was recently sold to Republic Aviation Corporation (q.v.). This move by the Fairchild Engine Division from its Farmingdale plant in no way affects the status of the Division's plants at Valley Stream and Mineola, L.I., N.Y.

• **The Firestone Tire & Rubber Company. . .** A new $2,000,000 plant is now under construction in Los Angeles on a site adjacent to the company's main tire plant. The scheduled date for the completion of this project was not given. The new factory, in which the Corporal surface-to-surface missile will be manufactured, contains 350,000 sq.ft. of floor space and will augment present missile manufacturing facilities.

• **Fletcher Aviation Corporation. . .** The first and largest unit of Fletcher's new plant headquarters at the Fletcher-Rosemead Airport, Rosemead, Calif., was dedicated on June 30. This manufacturing unit has a total area of 121,000 sq.ft and is located on a 231-acre site that includes the airport. Further expansion announced by Fletcher for the Rosemead location will include a 150- by 200-ft., two-story administration building. Additional sites adjacent to the Fletcher-Rosemead Airport will be leased to other manufacturers after the completion of Fletcher projects and runway improvements, it was announced.

• **General Electric Company. . .** A new aluminum-to-ceramic process, developed by General Electric, is reported to permit lightweight aluminum to be used in place of heavier conventional metals in many electrical applications. G-E's General Engineering Laboratory says the new process can be used to advantage in making capacitors, high-speed relay switches, aircraft instruments panels, and ignition systems, as well as other items requiring

The U.S. Air Force's new B-57B light bomber, built by The Glenn L. Martin Company, is shown with a full complement of explosives under the wings—four napalm tanks and eight 5-in. high-velocity aircraft rockets. Eight 50-cal. machine guns fire from the wings' leading edges. This latest version of the B-57 includes among its new features: (1) a completely redesigned cockpit that gives greatly improved visibility for the two crewmen (pilot and navigator-radar operator-bombardier); (2) hydraulically operated speed brakes that have been added to the aft portion of the fuselage and are roughly triangular in shape; and (3) the Martin-developed rotary bomb door that permits the bombs to be carried internally until the target is reached and then to be revolved with the door 180° into drop position.

insulated hermetic seals. In this new G-E process, the ceramic section to be joined to aluminum is coated with an alloy. Molten aluminum is then alloyed to the coated ceramic. The resulting dense aluminum layer around the ceramic is machined to the required diameter and brazed into the aluminum structure for which the ceramic seal was designed. . . . The Aircraft Products Department at Johnson City, N.Y., is scheduled to have one of the most modern indoor firing ranges in the country, according to a recent company announcement. The range will include an all-angle lane that will allow a bomber armament system to be fired through all its horizontal and vertical angles. It will also be equipped with facilities permitting the environment-controlled testing of aircraft armament systems. These facilities, located in a soundproof building, will be used additionally for both production and development testing of new armament systems. . . .A new division, known as the Chemical and Metallurgical Division, has been formed from the former Chemical Division and the Carboloy Department. The former Chemical Division's four operating departments remain unaffected under the new organization arrangement. The Chemical and Metallurgical Division now has five operating departments: Carboloy, Plastics, Silicon Products, Chemical Materials, and Laminated and Insulating Products. . . .An 8-page, two-color bulletin, designated GEA-6115, describes G-E's new Small Aircraft Engine Department set up within the Aircraft Gas Turbine Division. This bulletin, available from the company's Schenectady, N.Y., office, covers the department's facilities, engineering talent, and possible new engine designs. It discusses and illustrates the small aircraft engines currently under consideration, which include helicopter, turbojet, turboprop, and ducted-fan engines.

• **The B. F. Goodrich Company.** . .A dynamometer, recently installed at the Goodrich wheel and brake plant at Troy, Ohio, has a present top speed of 246 m.p.h. with provision for future speeds up to 300 m.p.h. This new airplane brake-testing machine permits the testing of a wheel loaded to 70,000 lbs. and traveling at 246 m.p.h. Such tests simulate stresses sustained by wheels and brakes in landing and safely stopping today's large aircraft where the individual wheels must support loads up to 25 tons. This machine, which weighs 113 tons and stands 9 ft. high, is said by the company to be the only dynamometer equipped with apparatus to duplicate the effects of windage and aerodynamic drag met in actual aircraft landings.

• **Goodyear Tire & Rubber Company and Boeing Airplane Company.** . .Engineers from Goodyear and Boeing have cooperated in developing a fan blade made entirely of a fiber-glass reinforced plastic for use in Boeing's privately owned transonic wind tunnel at Seattle. The basic blade design is a hollow fiber-glass shell filled with alkyd plastic foam for additional stiffness. The fan section of the Boeing tunnel consists of a two-stage fan with a 24-ft. diameter. There are 72 3-ft. fiberglass blades in two rotors and 67 fixed-steel stator blades. The fan hub is of pre-

HOT UNDER THE COLLAR . .

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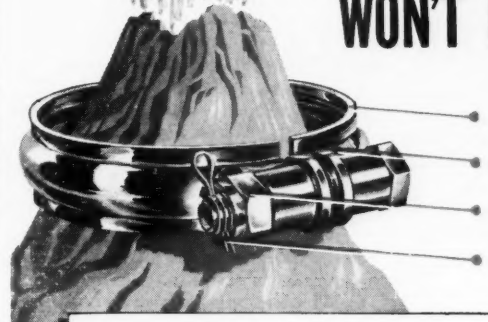

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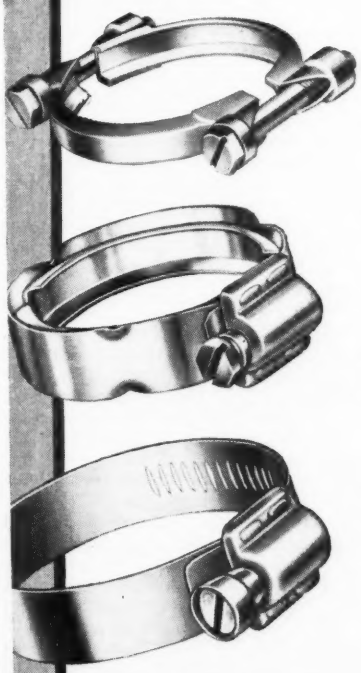

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A jet engine exhaust is a volcano of heat, pressure and vibration. The clamp that goes around it must withstand these conditions—and *hold tight.*

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cision-machined steel and aluminum and is housed by an 18-ft.-diameter tear-drop nacelle with external cooling air duct. The fan operates to a maximum speed of 480 r.p.m. The test section of the tunnel measures 8 ft. high by 12 ft. wide and, for high-speed test purposes, can accommodate scale models with wing spans up to 9 ft. At lower speeds, larger models can be used. Two motors, coupled together, produce a total of 54,000 hp. and drive the fan at top speed.

• **Grumman Aircraft Engineering Corporation. . .** A Grumman S2F-1 sub-killer has the distinction of being the first plane to be launched from a steam catapult aboard an American aircraft carrier. The carrier was the U.S.S. "Hancock," and the event took place fairly recently off San Diego, Calif. The U.S. Navy's carrier-conversion program calls for the installation of British-developed steam catapults on 13 carriers.

• **Jack & Heintz, Inc. . . .** A new lightweight a.c. generator has been developed for operation at the extremely severe temperatures encountered by high-performance aircraft. This is a 40-kva. 3-phase 400-cycle unit that will supply power for the instruments, radar, radio, fire control, and other aircraft devices requiring a.c. electric power. This new Jack & Heintz generator measures approximately $10^1/_4$ in. in diameter and 16 in. overall and weighs 86 lbs. The unit is designed in accordance with MIL-G-6099 and Air Force Drawing 53C6956. It operates at 6,000 r.p.m. at 208/120 volts with a power factor as low as 0.75.

• **Walter Kidde & Company, Inc. . . .** Crash fire prevention equipment, initially researched by the NACA, is being perfected by Kidde under a USAF contract. Company engineers are testing devices that are said to operate effectively to prevent fire in either simulated or real crash conditions. Kidde states that "certain combinations of reaction, deformation, and inertia switches trigger the systems electrically at the moment of impact. After 0.008 sec., they spray the nacelles with a solution which both cools and inerts them with fog; inerts the induction system with carbon dioxide; shuts off gas, oil, and hydraulic systems; actuates all normal fire extinguishing systems; and turns off all electrical systems. Within 2 sec. from the crash impact, the equipment has done its work." Kidde engineers state further that for the four-engined DC-7 the crash fire prevention equipment would weigh a total of about 500 lbs.

• **Lear Incorporated. .** A new type of electric remote positioning system, known as the "Electrolink," has been developed by the Lear Grand Rapids Division. It is said by the company to extend the useful power range of electric servomechanisms in the aviation and industrial fields. The Electrolink has three components: an electric amplifier, a transmitter autosyn, and a magnetic-powder-clutch servodrive with integral receiver autosyn. The complete system weighs 10.5 lbs. . . . Model 2217A VHF Broad Band Communications Antenna, developed by the LearCal Division, has been approved by the CAA for installation on aircraft engaged in scheduled interstate, foreign, and overseas commerce. This antenna, made of an aluminum casting and weighing only 1 lb., 11 oz., was designed for radiation and reception of vertically polarized communications signals in the 118 to 140 mc. frequency range. This equipment, externally mounted on the skin of the aircraft, is now in production.

• **Lockheed Aircraft Corporation. . .** The Georgia Division is now carrying out a USAF modification and IRAN program on the B-47 Stratojet bomber. This is in addition to the current production of new B-47's and C-130A's. The C-130A is a cargo aircraft powered by four Allison turboprop T-56 engines.

• **McDonnell Aircraft Corporation. . .** The F-101, McDonnell's twin-engined long-range escort fighter, is reportedly making its first flight at Edwards AFB, Calif., "sometime this fall." The F-101 is powered by two Pratt & Whitney J57 turbojet engines. It is also reported that McDonnell's XHCH-1, a ship-to-shore short-haul cargo helicopter for the Navy, will make its first flight within the next few months. . . .It was announced in McDonnell's "15th Annual Report," dated June 30, 1954, that, beginning with the sixty-first Navy F3H Demon, many improvements in air frame and equipment are being incorporated in the airplane. The new version of this carrier-based general purpose fighter, designated the F3H-2N Demon, is being powered by the Allison J-71 turbojet engine. (Previous Demons were powered with the Westinghouse J-40 turbojet engine.) The Report also stated that the Army Air Force XV-1 reconnaissance convertiplane (previously XH-35) had completed extensive full-scale wind-tunnel tests last May and had started on a flight-test development program. . . .It was announced in August that the first productive tests had been started on the recently completed $1,000,000 wind tunnel at Lambert Field, St. Louis, Mo. The first model tested was a scale replica of the XV-1 convertiplane. This tunnel, which has a test section measuring 8 ft., 6 in. by 12 ft., was built for investigation of low-speed characteristics of high-speed aircraft and missiles and for development of helicopters throughout their complete speed range. The St. Louis tunnel supplements the $8,000,000 Southern California Cooperative Wind Tunnel, which is being modified to permit transonic and supersonic testing and in which McDonnell has a one-sixth interest . . . .A group of 45 engineers and technicians moved during this past summer to Edwards AFB, Calif., to conduct a classified flight-test program over a period of approximately 1 year.

• **Minneapolis - Honeywell Regulator Company. .** Two high-performance push-pull magnetic amplifiers, recently developed by the company's Aeronautical Division, feature special core configurations and automatic self-bias. They are designed to give proportional control of valves or servomotors requiring from 3 to 30 watts of push-pull power. The 3-watt unit, designated the XEG52A amplifier, weighs 8 oz. and occupies 10 cu.in. of space. The 30-watt amplifier, called the XEG46B, weighs 2 lbs. and takes up 40 cu.in. of space. Either unit can be driven to full output by a 1-milliamp. signal from a subminiature tube or transistor. The delay constant approximates 5 millisec. For use without vacuum tubes, both units are available in cascaded combinations for microwatt signal level operation. The new amplifiers are designed for a minimum operational life of 10,000 hours.

• **North American Aviation, Inc. . . .** Three jet silencer units have been added to North American's sound-abatement system at the company's fighter assembly line at Los Angeles International Airport. These new facilities will be used in ground operations of the F-100 Super Sabre and for acceptance testing of Pratt & Whitney J-57 engines. Eight other sound-reduction units are in use by North American for ground operations of the F-86 Sabre series, the first of these being placed in operation during 1948. . . .An agreement has been signed by North American and Shin Mitsubishi Reorganized, Ltd., of Tokyo, Japan, whereby the Japanese company would receive limited rights to repair and manufacture parts for USAF F-86's stationed in the Far East. This proposal has been submitted to the U.S. Government for approval. Under the terms of this agreement, North American would supply technical personnel, engineering data, and production data on the Sabre, and Mitsubishi would manufacture only nonstructural spare parts. Under separate contract, the plant would repair and overhaul F-86's for the Far East Air Force.

• **Northrop Aircraft, Inc. . . .** The F-89D Scorpion has been equipped with two auxiliary pylon fuel tanks to increase the fighter's range. Mounted beneath the wings about midway between the fuselage and wing-tip rocket pods, these tanks are said not to affect the speed of aircraft appreciably. When empty, they may be jettisoned by an explosive cartridge triggered by the ship's pilot. These tanks, each of which is nearly 15 ft. long, together weigh more than 2 tons when filled with fuel. The two wing-tip pods of the F-89D carry 104 air-to-air rockets. This twin-jet aircraft is powered by Allison-built turbojets with afterburners. . . . Several hundred thousand dollars' worth of new equipment has been installed in the company's Materials and Process Laboratory to permit a specialized investigation into the problems associated with the "thermal barrier." This newly equipped engineering laboratory is divided into four sections: the Chemical Section, which handles work on finishes, corrosion problems, and sealing; the Metallurgical Section, which does physical testing and microscopic examination; the Non-Metallic Section, which handles the investigation and development work on plastic laminates, rubber elastomers, structural adhesives, textiles, thermal and acoustic insulation, transparent plastics, glass, and electrical materials; and the Machine Shop, which is used for the fabrication of physical test specimens. . . .Construction on a new 198,000-sq.ft. materiel warehouse at Northrop's El Segundo, Calif., facility, was begun on August 5. This new structure, scheduled for completion by January 1, will provide for complete centraliza-

tion of all Northrop materiel functions and will be a direct adjunct to Northrop's existing 80,800-sq.ft. Maple Ave. building in El Segundo.

• **Pan American World Airways, Inc. . . .** The purchase of 15 Douglas DC-7C's, at a total cost of approximately $33,000,000, was recently announced by Pan American. Deliveries of the new airplanes will begin in early 1956. The DC-7C, which will be powered by four Wright turbo-compound DA-4 engines, will cruise at 365 m.p.h. and will have a 5,000-mile range. In its new configuration, the DC-7C has a wing span of 127 ft., 6 in.—10 ft. longer than the present DC-7's. This wing extension allows a substantial increase in the fuel capacity and the relocation of the inboard engines 5 ft. further away from the fuselage, thus lowering the noise level. . . .The DC-3 has undergone certain modifications at Pan American's Miami, Fla., Overhaul Base which put this twin-engined Douglas transport into the 200-m.p.h. class, give it an additional range of 600 miles, and increase its net pay load by 1,528 lbs. These modifications, which have added only 172 lbs. to the plane, include the replacement of the 1,200-hp. R-1830 engine that normally powers the DC-3 by the 1,450-hp. R-2000 engine used in the DC-4. Supplementing these larger engines are extra wing tanks—increasing the fuel capacity by 420 gals.—as well as new propellers, a heavier landing gear, and other improvements. The R-2000 DC-3 modification is now available to other DC-3 owners at Pan American's Brownsville, Tex., Customer Base. The CAA-approved engineering data for the changes are being made available by Pan American to other air lines, fixed-base operators, and executive aircraft owners. . . A new booklet, "Currency Converter," has been issued by Pan American to help the traveler translate foreign currency into American money. This booklet also lists what may be taken into and out of various countries and includes charts for distance, volume, temperature, and weight, converting these measurements from the metric system. It is available at any Pan American office or may be obtained by writing the company at P.O. Box 1111, New York 17. . . .James E. McGuire, who has been with the company for 11 years, was elected Assistant Comptroller of Pan American.

• **Piasecki Helicopter Corporation. . .**A Certificate of Meritorious Performance to the Navy's Helicopter Utility Squadron HU-2, Lakehurst NAS, N.J., was issued by the corporation over the signatures of Frank N. Piasecki, FIAS, Chairman of the Board, and Don R. Berlin, FIAS, President. This certificate was awarded on June 22 "in recognition of the outstanding performance of Squadron HU-2 for accumulating over 25,000 hours of flight time in the HUP-type helicopter." The first production HUP's were delivered to Lakehurst in 1951; the last HUP helicopter was delivered to this squadron on last July 1.

• **Pratt & Whitney Aircraft Division, United Aircraft Corporation. . .**The development by Pratt & Whitney of a nickel-based heat-resisting alloy for jet-engine turbine blades and the availability

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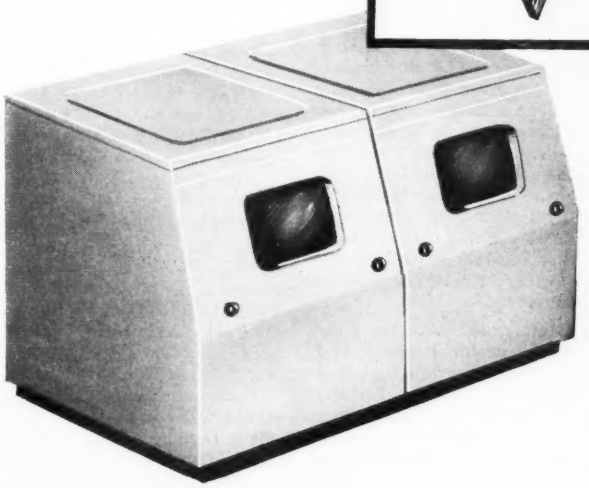

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of this alloy to other jet-engine manufacturers, without license fee or royalty, has been announced. This alloy, called "Waspaloy," has boosted the power rating of the company's centrifugal-flow J-48 turbojet engine, which now has a basic thrust of 7,250 lbs. The company says that Waspaloy's superior heat-resisting properties permit the engine to operate at higher turbine temperatures for longer periods of time than was previously possible. Waspaloy has a base of more than 50 per cent nickel to which varying amounts of chromium, cobalt, molybdenum, titanium, and aluminum are added. The first Waspaloy rolled bar stock was produced in 1949 to Pratt & Whitney specification by Allegheny Ludlum Steel Corporation and was converted into rough blade forgings by Utica Drop Forge & Tool Corporation. The forgings were machined by Pratt & Whitney and were subjected to hundreds of tests in their development laboratories. The first test-stand run of a J-48 turbine fully fitted with Waspaloy blades was made early in 1950. According to the company, an increase of more than 10 per cent over the engine's previous basic thrust was obtained from this single change. Processing improvements have further increased the life of Waspaloy blades.

• **Reaction Motors, Inc.** . . .Dr. Fred Olsen, Vice-President for Research and Development, Olin Industries, Inc., and Hans A. Klagsbrunn, Senior Partner, Klagsbrunn, Hanes and Irwin, have been elected to the corporation's Board of Directors. This brings the Board's total membership to nine.

• **Republic Aviation Corporation.** . .Arrangements to purchase the factory and office building now occupied by Fairchild Engine and Airplane Corporation's Fairchild Engine Division (q.v.) at Farmingdale, L.I., N.Y., have been completed. The acquisition of this 424,000-sq.ft. building will enable Republic to consolidate its essential engineering and experimental operations closer to its Farmingdale plant. Republic's personnel operating in leased facilities at Port Washington, Greenlawn, Hicksville, and Montauk will not be affected by the purchase of this Fairchild plant. . . .The engineering personnel assigned to the F-105 fighter-bomber project have been transferred from the offices in New York City to the main assembly plant at Farmingdale, L.I., N.Y. This move is designed to speed up the work on the F-105 by bringing the engineering and production personnel concerned with this project in closer proximity.

• **Summers Gyroscope Company.** . .Two light-plane autopilots are being developed by Summers for the U.S. Army Signal Corps. One of these is to be a single-axis autopilot designed to control an aircraft solely about its roll axis. The second one will be a two-axis autopilot that will control a light aircraft about both roll and yaw axes. Summers is also developing under a joint USAF–USA Signal Corps contract a full three-axis autopilot.

• **United Air Lines, Inc.** . . .Two flight simulators, purchased by United from Curtiss-Wright Corporation, have been installed at the air line's new training center at Chicago's Midway Airport. These two simulators duplicate the performance of the Douglas DC-6B and Convair 340 aircraft. The pair in Chicago are an addition to two others located at United's long-established Denver (Colo.) flight training center. These simulators are said by United to be the first acquired by a domestic air line and the largest number placed in service by any air line. The four simulators represent an investment of more than $3,000,000.

• **Vickers, Inc.** . . .A 4-page brochure, available from Vickers, describes the airborne applications of a hydraulic winch system for helicopters.

IAS Sections

Baltimore Section

Raymond D. Blakeslee, *Secretary*

The fifty-second meeting of the Baltimore Section of the Institute of the Aeronautical Sciences was held in Levering Hall of The Johns Hopkins University on Thursday, June 24, at 7:00 p.m. An enjoyable cocktail hour in the Aeronautical Building and an excellent dinner in Levering Hall preceded the formal meeting.

G. F. Towner, Chairman, presided and introduced the speaker of the evening, Brig. Gen. L. I. Davis, USAF, Assistant for Development and Supporting Research, Air Research and Development Command. General Davis spoke on the subject of "The Dynamics of Air Warfare." With the aid of slides, General Davis discussed optimal air warfare strategies and their payoffs, using the basic principles of game theory.

Following the guest speaker's presentation and a short discussion period, announcement was made of the election of officers for 1954–1955.

The meeting was turned over to H. Pusin, the newly elected Chairman, who, in behalf of all the newly elected officers, closed the meeting with a statement of intent to continue the fine work of the Baltimore Section during the forthcoming year and a request for continued active membership support.

Boston Section

E. L. Dashefsky
Outgoing Secretary

The annual dinner meeting of the Boston Section of the Institute of the Aeronautical Sciences was held at the Thompson Club, Nahant, Mass., on May 25. A cocktail hour, sponsored by General Electric Company's Aircraft Gas Turbine Division at Lynn, began at 6:00 p.m. and was attended by approximately 100 members and guests. Following the dinner, the newly elected officers for the 1954–1955 season were announced. They are: Chairman, Joseph J. Jerger; Vice-Chairman, Robert L. Halfman; Secretary, John B. Tucker; and Treasurer, Edward L. Dashefsky.

The outgoing Chairman, John D. Morrison, of General Electric, introduced the speaker for the evening, John R. Wiley, Deputy Director of Aviation, Port of New York Authority. Mr. Wiley delivered an interesting and enlightening talk, illustrated with slides, on "Airports and Air Transportation." The paper covered in general the system of airports in and around New York City, the magnitude of the operation and the air traffic passing through this area, the noise and nuisance adjacent to airports, and helicopter operations in the New York area.

Mr. Wiley's paper was followed by a discussion period of about 30 min. The meeting was adjourned at 10:30 p.m.

Cleveland-Akron Section

R. T. Hall
Outgoing Secretary-Treasurer

The following have been elected to serve as officers of the Cleveland-Akron Section for the 1954–1955 year: Chairman, E. J. Manganiello; Vice-Chairman (Cleveland), F. M. Hopkins, Jr.; Vice-Chairman (Akron), John Boshar; Secretary, Howard F. Powders; and Treasurer, Bruce T. Lundin. The members of the Advisory Board are C. M. Bolster, R. E. Bolz, J. W. Ebert, R. T. Hall, L. A. Rodert, E. R. Sharp, Abe Silverstein, and E. C. Sulzman.

Dayton Section

G. R. Graetzer, *Secretary*

George J. McTigue, General Electric Company, has been elected Chairman of the Dayton Section, Institute of the Aeronautical Sciences. Other officers, whose elections were announced on June 8 at a meeting of the group at Wright-Patterson AFB, Ohio, are: Vice-Chairman, W. Donald Dodd, Jr.; Secretary, Gunther R. Graetzer; and Treasurer, T. J. Keating. Messrs. Dodd, Graetzer, and Keating are Air Force employees at Wright-Patterson.

Elected to the Section's Council were Charles Hall, Bell Aircraft Corporation, and D. G. Samaras, F. E. Null, and N. M. Thorne, all of WPAFB.

After the business meeting, the group toured the Propeller Laboratory of the Wright Air Development Center and

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The 1954–1955 Officers and Advisory Board members of the IAS Hampton Roads Section are shown here. Seated *(left to right)* are five members of the Advisory Board: Jean Roché, H. J. E. Reid, Melvin Gough, Herbert Jackson, and William Alford. Standing *(left to right)* are: Vice-Chairman Robert Pendley; Corresponding Secretary Richard Kuhn; Chairman Emanuel Boxer; Treasurer Franklin Diederich; and Recording Secretary William McCauley.

heard Col. L. M. Taylor, Chief of the Laboratory, discuss recent propeller and rotary-wing developments in a talk on "Where We Are Now and Where We Are Going."

Hampton Roads Section

JOHN E. Duberg
Outgoing Recording Secretary

On July 7, the final meeting of the 1953–1954 year of the Hampton Roads Section of the IAS was held at the NACA Morale Activities Building; 37 members and guests were present. The meeting was also attended by members of the Icarian Flying Club and those Student Members of the IAS employed for the summer by the NACA.

The program consisted of three motion pictures made available by North American Aviation, Inc., and the Los Angeles Section of the IAS. They were: *Development of the Spitfire*, a production of Vickers-Armstrongs, Ltd., which traces the development of the Spitfire from the 1925 Schneider cup racer; *Carrier Evaluation Tests of the FJ-1*, a color film of the test of six FJ-1 aircraft on May 3 and 4, 1949, in landings, free take-offs, and catapult take-offs from the aircraft carrier "Princeton"; *Eighth Air Force Fighter Combat Film*, a collection of gun camera films of ground strafing and aerial combat in Europe during 1944.

Announcement of the results of the election of next year's officers was made by Chairman Herbert Jackson, as follows: Chairman, Emanuel Boxer, Vice-Chairman, Robert Pendley; Treasurer, Franklin Diederich; Corresponding Secretary, Richard Kuhn; and Recording Secretary, William McCauley. The Advisory Board consists of Capt. Sheldon Brown and Messrs. Melvin Gough, H. J. E. Reid, Jean Roché, Charles Zimmerman, Herbert Jackson, and William Alford.

Los Angeles Section

Evert C. Hokanson, *Secretary*

"Pegasus and the Helicopter" was the title of the paper Howard E. Roberts presented at the June 17 dinner meeting of the Los Angeles Section. Mr. Roberts, Director of Operations, American Helicopter Division of Fairchild Engine and Airplane Corporation, gave a broad analysis of transportation and the role that the helicopter might be expected to take in the future.

The winged horse, Pegasus, and the helicopter are both old ideas that have much in common. Pegasus remains with us today as a bit of Greek mythology, while the helicopter has developed into a most versatile mode of transportation. However, before the helicopter can take a leading part in our present transportation system, it still needs to undergo certain improvements.

Mr. Roberts listed the five basic factors that determine the selection of a given mode of transportation. They are (1) psychological acceptance, (2) safety acceptance, (3) convenience, (4) comfort, and (5) economy. With the assistance of slides, each factor was analyzed in detail in relation to accepted modes of transportation. The general public and operator accepted the helicopter psychologically from its first flight. In regard to safety, statistics to date have proved it to be most remarkable. This good safety record can be maintained if newer and larger types are not pushed into service before they have undergone a thorough operational "debugging period." The helicopter rates high from the convenience factor standpoint because of its inherent versatility. It is superior to other means of transportation in block-to-block speeds in ranges from 5 to 200 miles. It is not subject to surface congestion of highways in metropolitan areas.

However, on the negative side, improvements can be made to reduce maintenance requirements and increase service life. There is still much to be desired in comfort. The primary objection is noise; vibration is secondary. As increased comfort means increased weight, the degree of comfort incorporated will be dependent on the trip length The helicopter is economical in time but not in cost, as of this date. These high costs can be expected to come down as the costs resulting from direct and indirect maintenance and depreciation of equipment are lessened. Maintenance and depreciation represent the major part of the total operating cost per hour of flight. The success of the helicopter as an economical mode of transportation will depend primarily on the concentrated effort of helicopter manufacturers to improve and simplify their designs so as to decrease initial cost and reduce maintenance and inspection time.

Developed to the stage where it will divert only 3 per cent of passenger miles of private automobiles, the helicopter would handle the equivalent now handled by the entire air-transportation industry. Because of the superiority of the helicopter in the 5- to 200-mile range, it can be expected to divert passenger traffic from bus and rail lines but not from the air lines.

At the present rate of development, Mr. Roberts concluded, it may take 1 or 2 decades before we can expect the helicopter to "come of age."

Mr. Heppe presided at the meeting. He introduced the speaker and honored guests from the New York IAS office: Miss Marjorie Rodé, Mr. and Mrs. Welman A. Shrader, and Robert R. Dexter.

▶ On June 10, Bernard Mazelsky, Dynamics Engineer, Lockheed Aircraft Corporation, presented a paper on "Extension of Power Spectral Methods of Generalized Harmonic Analysis and Application to Aircraft Problems." This specialist meeting, attended by 35 people, covered the subject in three phases: the background and development of theoretical approach to the methods; the application of the methods to the analysis of airplane response problems, primarily those associated with gust-load problems; and the results obtained from applying the methods to specific aircraft problems. During the discussion following the paper, it was concluded that the methods presented provide a useful tool for airplane analysis to the dynamics engineer. Richard Boyles, Member, Specialist Meeting Committee, presided.

Cold Frontier

Up where summers are cold and winters colder, where days are long and nights seem longer, U. S. Air Force men in Northrop Scorpion F-89 interceptors stand all-weather guard along our northern frontier. These reliable bomber destroyers fly through icy fog, storm and blackness to give around-the-clock protection to the heartland of America. Northrop Scorpions have speed to intercept invading aircraft, the endurance and firepower to follow, harass, and destroy them long before they can reach their intended target. F-89's are one of many contributions to national defense made by the experienced engineering and production complex of Northrop Aircraft, Inc., America's first company in the vital design, development and production of all-weather and pilotless aircraft.

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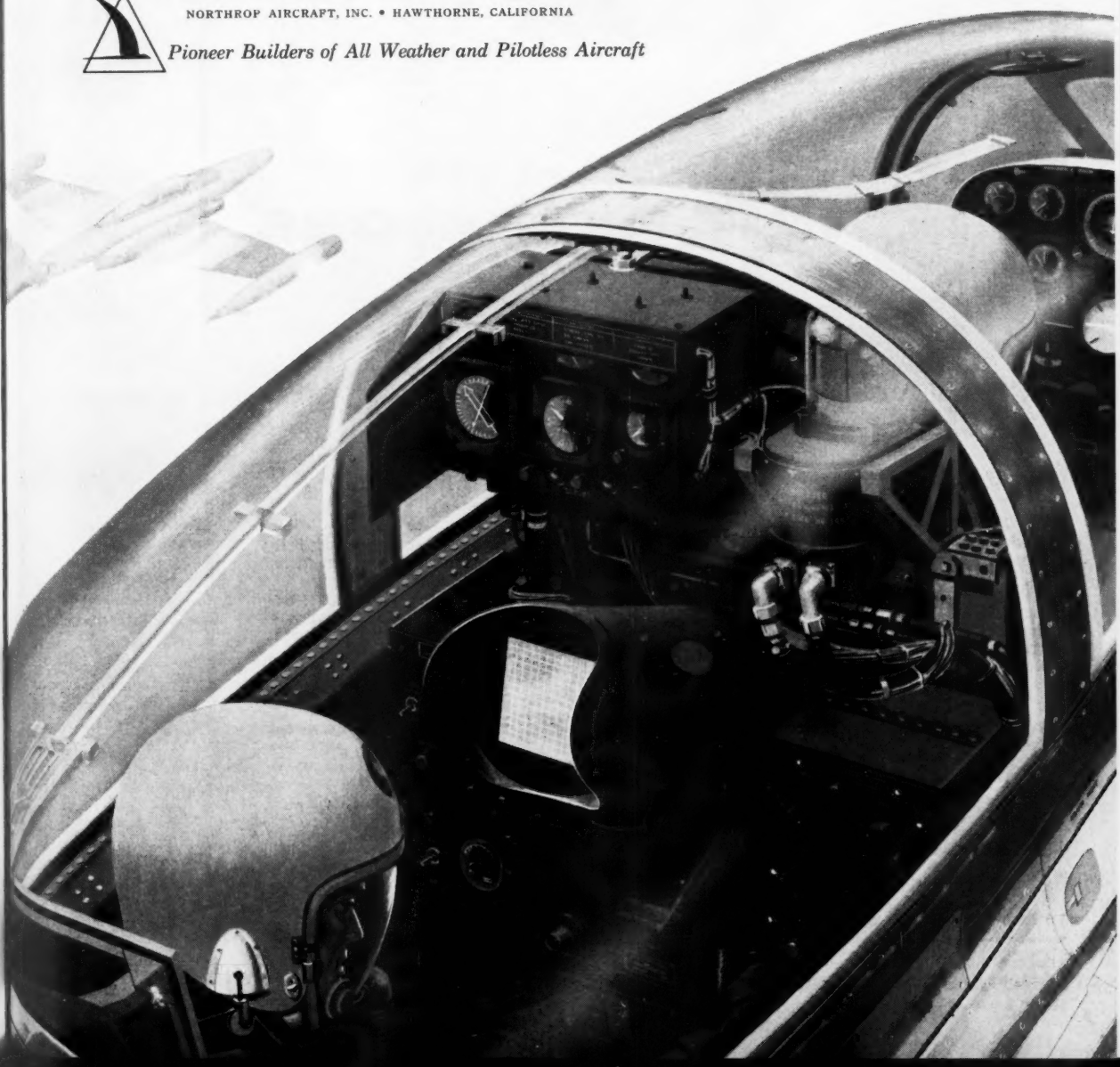

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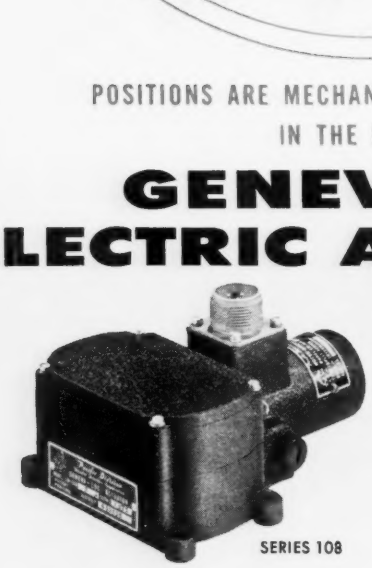

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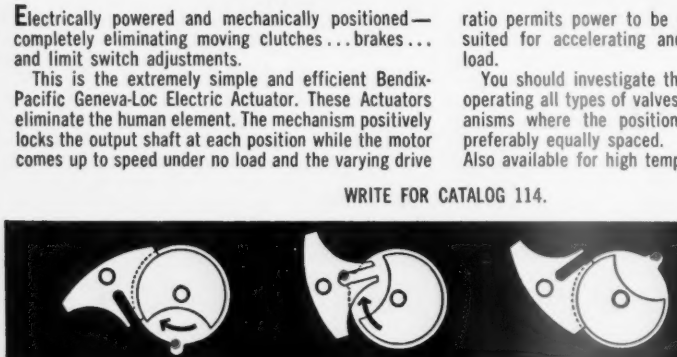

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St. Louis Section

A. H. Madrick
Publicity Chairman

The St. Louis Section held its annual election of officers during the latter part of June. A slate of candidates was prepared and submitted by the Nominating Committee under the chairmanship of Will Wells. The balloting was conducted by mail, and a 50 per cent return from the membership was realized.

Official installation of the officers will not take place until the first meeting of the 1954–1955 season. The newly elected officers will, however, utilize the summer months as a period of indoctrination and orientation. In this way, the Section can be assured of the smoothest possible transfer of responsibility so ably borne by the retiring officers.

The results of the election are as follows: Chairman, Edward M. (Bud) Flesh; Vice-Chairman, Fred L. Doblhoff; Secretary, Larry A. Smith; and Treasurer, William H. Rivers. The members of the Advisory Board are: Charles H. Hurkamp; Capt. Charles H. S. Murphy, USN; J. H. Meyer; and Vernon Outman.

The Section wishes to thank its outgoing officers for their untiring efforts in making the 1953–1954 season a great success. It also wants to extend a hearty welcome to the incoming officers and to express its confidence that the 1954–1955 season will surpass all previous ones in achievement.

San Diego Section

H. C. Matteson
Corresponding Secretary

"How the Air Force Develops and Procures Complex Weapons Systems" was the title of a talk given before the San Diego Section on July 20 by Brig. Gen. Floyd B. Wood, USAF. General Wood, as Deputy Commander for Technical Operations of the Air Research and Development Command, was well qualified to discuss this comparatively new concept of weapons procurement.

The speaker opened his talk by pointing out the need for the weapons system concept and then described this concept. He outlined the roles played by the USAF and other federal agencies as well as by industry under this system of weapons development and procurement. General Wood reviewed the manner in which the need for a new weapon is determined. He included in his remarks a discussion of the division of responsibility between the Air Force, the prime contractor, and the associate contractors in the weapons development and construction program.

General Wood's audience of approximately 100 members and guests was

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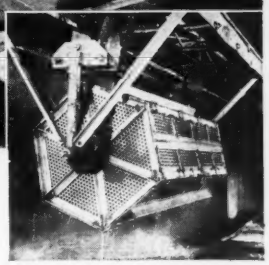

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favorably impressed by the clear manner in which the speaker dealt with this complex subject.

Seattle Section

J. C. Baer, *Treasurer*

The Seattle Section was fortunate in hearing Dr. H. W. Liepmann, of the California Institute of Technology, talk on the subject of "Aerodynamic Noise" at our May 19 meeting.

Dr. Liepmann, an outstanding experimental aerodynamicist, has made noteworthy contributions to the understanding of fluid-flow phenomena during the past decade. His major investigations have been in the fields of transonic flow, shock waves, boundary layer, and turbulence. In addition to his teaching and research activities at CalTech, Dr. Liepmann has been a Consultant in Aerodynamics to the Douglas Aircraft Company since 1944.

The meeting was held at the University of Washington where Dr. Liepmann has been a Walker-Ames lecturer. He was introduced by Dr. Harold Martin, of the University of Washington Aeronautical Engineering School.

Dr. Liepmann defined aerodynamic noise as that associated with air itself and pointed out the different ways in which sound is generated. He stressed the magnitude of present noise problems and indicated that in a large percentage of cases modern airplane noise comes from aerodynamic noise associated with the boundary layer. As a matter of interest, he mentioned that radio reception in an automobile traveling at 70 m.p.h. is noticeably affected by boundary-layer wake noise.

Dr. Liepmann indicated that current experimental results show noise intensity for a jet to be proportional to the product of the square of the diameter and the velocity to the sixth to eighth power. This suggests noise reduction by moving a large body of air slowly instead of moving a small body of air at high speed. As he pointed out, this is not always a practical thing to do.

Dr. Liepmann suggested that noise is one of those cases in science where it is often impossible to understand the subject fully and to get a practical answer. A question-and-answer period followed the talk.

Russell B. Light, *Secretary*

The June 16 dinner meeting of the Seattle Section was held at Inglewood Country Club. The dinner was preceded by an enjoyable social hour.

Dan Downey, Boeing Airplane Company, was the principal speaker of the evening. Mr. Downey has been a member of Boeing's power-plant staff for 12 years and is currently the Group Engineer in charge of power-plant development for the jet tanker-transport series.

The subject of Mr. Downey's talk was "The Gas Turbine in the Aircraft Power-Plant Field." He clarified his subject at the outset by systematically classifying gas-turbine types under three main categories: (1) turbojet, (2) by-pass, and (3) turboprop. Slides were used to illustrate the major differences of the engine types. Within the limits of security and proprietary rights, he discussed the advantages and disadvantages of refinements on each of the various engine types. Mr. Downey concluded his talk with a brief discussion of the factors involved in the selection of an engine type for a particular application and the relative utility of each of the three main categories. A discussion period followed the talk.

▶ The July 14 dinner meeting of the Seattle Section was held at the Seattle-Tacoma Airport.

This meeting was planned to give a behind-the-scene view of the vast network of traffic control facilities required to support United States airways operations.

A. T. Curren, former American Airlines, Inc., Engineering Pilot and currently with Boeing Airplane Company's Aerodynamics Unit, made a hypothetical instrument flight from Portland, Ore., to Seattle, Wash., outlining the procedures and equipment utilized for navigation, communication, airport approach, and let-down.

William Flenner, Senior Airways Traffic Controller with the Civil Aeronautics Administration, supplied the ground link on the hypothetical trip and reviewed the ground-support provided for the flight, describing the radio, radar, and communications facilities used.

This presentation was followed by a tour of the Seattle-Tacoma Airport Control Tower, surveillance radar facilities, United States Weather Bureau, and the air-lines radio installation (Air Radio Incorporated).

The behind-the-scene activities were indeed impressive, and we are indebted to the CAA, the United States Weather Bureau, and Air Radio Incorporated for the opportunity to view these operations.

A group of IAS Student Members of the Academy of Aeronautics Student Branch are shown before a Colonial Airline transport during their June 11 field trip to NACA's Langley Aeronautical Laboratory.

Student Branches

Academy of Aeronautics

R. Zincone and W. A. Gatehouse, Jr.
Student Members

On June 11, the members of the IAS Student Branch at the Academy of Aeronautics had the privilege of visiting the NACA Langley Aeronautical Laboratory at Langley Field, Va. In order to save time, arrangements were made with Colonial Airlines, Inc., to fly the IAS Student Members to Langley Field. Upon our arrival there, we were greeted by Mr. Fedzok, a Research Engineer. Mr. Fedzok told us about the three laboratories operated by the NACA and briefly described the types of experiments that take place in each one. At the conclusion of his talk, a tour of the Langley facilities was begun.

One of the most interesting stops along our tour was the Hydrodynamics Department, where tests are run on all equipment concerned with seaplane operation. During our visit in this department, a test was being conducted to

determine the effects of different ditching methods. The hydro-tank here is one of the largest in the country, measuring 1,800 ft. in length, 18 ft. in width, and 6 ft. in depth.

We were shown many different wind tunnels at this laboratory. These included tunnels for use in subsonic, transonic, and supersonic testing. While we were at the transonic wind tunnel, a test was in progress on two helicopter blades that had freedom about the flapping hinge but no freedom about the lag hinge. The purpose of this test was to plot a group of curves relative to blade-flapping motion.

In the vertical gust tunnel, we were shown how a plane with the elevator set high on the upper portion of the vertical surface recovered from a spin.

Replicas of the planes used in the various wind-tunnel tests are made in the Dynamics Model Shop. These models, constructed from fiber glass, are accurate to one hundredth of an inch. Each model takes about 600 man-hours to build.

It was agreed by the Student Members who went on the field trip that this was one of the most interesting ones the Branch has taken.

USAF Institute of Technology

Second Lieutenant Joseph Joyce
Secretary-Treasurer

Activities during the 1954 spring term were limited because Branch officers and many of the members were devoting all available time to thesis work.

New officers for 1954–1955 were elected at the June meeting. They are from a younger group of students, and it is felt they will have more time for planning and executing Student Branch activities. Officers elected are: Chairman, Capt. Leland S. Fields, Jr., USAF; Vice Chairman, 1st Lt. William C. Walter, USAF; Secretary-Treasurer, 2nd Lt. Joseph Joyce, USAF.

Following election proceedings at the June meeting, a film entitled *Aviation Oddities* was shown.

Dr. G. R. Graetzer, Faculty Adviser of the USAFIT Branch, was able to obtain as lecturer William B. Stout from Phoenix Ariz., to deliver a talk on "Ornithopters" in the USAFIT auditorium. Mr. Stout put forward some interesting theories on ornithopters, and his program was highlighted by the demonstration of working models. The program was attended by the Student Branch and many IAS members and engineers from the Wright Air Development Laboratories.

▶ The July meeting, held in the USAFIT auditorium, consisted of a full membership discussion of future activities and a film on the Air Force F-102.

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Members Elected

The following applicants for membership or applicants for change of previous grades have been admitted since the publication of the list in the last issue of the REVIEW.

Elected to Associate Fellow Grade

Boyd, Albert, Major Gen., USAF; Comdr., WADC, Wright-Patterson AFB.

Rogers, S. B., B.S.C.E., Engr., Grumman Aircraft Engineering Corp.

Schlatter, George F., B.S., Brig. Gen. & Deputy Chief of Staff, Operations, Hq. ATRC, USAF, Scott AFB.

Transferred to Associate Fellow Grade

Cleveland, Frank A., M.A., Bomber Dept. Mgr., Prelim. Design Div., Lockheed Aircraft Corp. (Burbank).

Elected to MEMBER Grade

Albert, Edward V., B.S. in M.E., Supvr., Transport Engine Product Planning, AGT Div., General Electric Co. (Cincinnati).

Atran, Leonard, M.S., Devel. Engr., Air Arm Div., Westinghouse Electric Corp.

Beeler, De Elroy, B.S. in M.E., (Aero.), Head Research Engr., High Speed Flight Station, NACA (Edwards, Calif.).

Christenson, C. M., Dir. of Safety, United Air Lines.

Craig, John, Jr., B.Sc. in Ae.E., Chief, Western Field Engrg., Pratt & Whitney Engines, United Aircraft Service Corp.

Denamur, H. G., Asst. to Managing Dir., Avions Marcel Dassault (Paris).

Eckard, L. Dillwyn, Jr., B.S.M.E. (Aero.), Asst. Proj. Engr., Flight Refueling, Inc.

Eliasson, Anders, Civ. Ing., Research Engr., Aircraft & Armament, Experimental Establishment, Royal Swedish Air Force.

Erickson, H. G., Dir. of Engrg. & Chief Engr., Temco Aircraft Corp.

Funk, William F., B.S. in E.E., Sr. Field Engr., Convair (Ft. Worth).

Gammal, Abraham A., S.M. in Math., Engrg. Specialist, Goodyear Aircraft Corp.

Garrett, William A., B.S.Ae.E., Design Engr., Vitro Corporation of America.

Halton, Harry, Engr. "A," Canadair, Ltd.

Hesse, W. J., Ph.D., Chief Engr., Test Pilot Training Div., NATC (Patuxent River); Visiting Prof. (part-time), Univ. of Maryland.

Hine, Ernest J., B.S.M.E., Flight Test Engr., Convair (San Diego).

Howard, Leroy A., B.S. in Ae.E., Gas Turbine Dept., Lycoming Div., Aviation Mfg. Corp.

Keck, Charles, B.S. in Ae.E., Engrg. Designer "A," Douglas Aircraft Co., Inc. (Santa Monica).

Lee, John David, Ph.D., Asst. Prof. & Research Assoc., Dept. of Aero. Engrg., The Ohio State Univ.

Owl, George A., Jr., B.S. in Ae.E., Sr. Designer–Engr., Design Analysis Sect., Confidential Design Group, North American Aviation, Inc. (Los Angeles).

Robinson, Samuel W., Jr., M.S. (Physics), Aircraft Dynamics Engr., Sr., Lockheed Aircraft Corp. (Marietta).

Schjelderup, Hassel C., Ph.D. (Engrg. Mechanics), Research Engr. "A," Northrop Aircraft, Inc.

Sussman, Harry, B. of E.E., Pres. & Chief Engr., Telectro Industries Corp.

Turci, John Delmo, M.Sc. in C.E., Research Engr., Lockheed Aircraft Corp. (Burbank).

Vess, James W., A.A., Design Engr., Engrg. Dept., Helicopter Div., Bell Aircraft Corp.

Webel, Lewis, B.S.M.E., Aero. Sales Engr., Sperry Gyroscope Co. (El Segundo).

Welch, Harmon C., B.S.C.E., Head, Aero. Design Br., Aerodynamics Lab., David Taylor Model Basin (Washington, D.C.).

Transferred to MEMBER Grade

Aron, Walter K., B.S. in M.E. (Aero.), Acting Head of Prelim. Design, Radioplane Co.

Gannett, James Russell, M.S.Ae.E., Exp. Pilot, Boeing Airplane Co. (Seattle).

Leland, Paul M., M.Sc. in Ae.E., Scientist, Rosemount Aero. Labs., Dept. of Aero. Engrg., Univ. of Minnesota.

Rosenthal, Frederick Albert, B.S. in M.E., Proj. Devel. Engr., Westinghouse Electric Corp.

Wallace, Charles W., Supvr., Aircraft & Services, Missiles Systems Div., HADC (Holloman, N.M.).

Elected to Associate Member Grade

Critchell, Howard M., First Officer, Co-Pilot, Western Airlines.

Fleming, Gilbert, Production Mgr., McDonnell Aircraft Corp.

Huegin, William B., B.S. (Business Admin.), District Product Mgr., Huck Mfg. Co.

Johnson, Harold G., Chief Sales Engr., Weber Aircraft Corp.

Mertz, P. John, Sales Engr., Sargent Engrg. Corp.

Otterson, Peder A., M.S., Asst. Prof., Aviation Tech., Kent State Univ.

Sorenson, Norman L., Flight Engr., Trans World Airlines (Chicago).

Turner, John F., Chief Engr., Weber Aircraft Corp.

Elected to Technical Member Grade

Hoefler, D. Gary, A.A.M.E., Lab. Engr., AiResearch Mfg. Co.

Kauffman, Douglas M., A.B., Engr., Flutter & Vibration Section, Fairchild Aircraft Div. (Hagerstown).

Kemmer, John P., B.S.Ae.E., Aerodynamicist "B," Ryan Aeronautical Co.

Loomis, Robert H., B.S. Engrg., Engr., Air Arm Div., Westinghouse Electric Corp.

Willis, Paul A., Field Engr., Sperry Gyroscope Co. Div., The Sperry Corp.

Transferred to Technical Member Grade

Ales, Robert E., Jr. Electronic Engr., Northrop Aircraft, Inc.

Anderson, David H., B.S. in A.E., Aviation Cadet–Pilot Training, USAF.

Arouchon, George J., B.S. in Ae.E., Jr. Aerodynamic Design Engr., Chance Vought Aircraft, Inc. (Boston).

Ball, Herbert Glenn, B. of Ae.E., Aerodynamics Engr., Convair (Ft. Worth).

Balser, Richard A., B.S., Student, Univ. of Washington.

Bartlett, Charles R., B.S. in Ae.E., Assoc. Engr. (Aerodynamics), The Glenn L. Martin Co.

Baumann, T. R., B. of Ae.E., Assoc. Engr.—Struct. Design, The Glenn L. Martin Co.

Beasley, Max D., Jr., B.S. in Ae.E., Aerodynamics Dept., McDonnell Aircraft Corp.

Beck, Clark J., Jr., B.S., Jr. Design Engr., Beech Aircraft Corp.

Blackwell, B. B., Aerodynamics Design Engr., Chance Vought Aircraft, Inc. (Dallas).

Blalock, R. J., Jr., B.M.E. (Aero.), Jr. Engr.—Aerodynamics Design, Douglas Aircraft Co., Inc. (Long Beach).

Bond, Richard A., B. of Ae.E., Research Engr., Grumman Aircraft Engineering Corp.

Browning, Bob D., B.S. in Ae.E., Lt., USAF; Proj. Engr., Wright-Patterson AFB.

Buery, Joseph F., Jr., B. of Ae.E., Assoc. Engr., Lockheed Aircraft Corp. (Marietta).

Burkett, James Edward, B.S. in Ae.E., Flight Test Analyst, Douglas Aircraft Co., Inc. (Santa Monica).

Cantrell, C. R., Jr., M.S. (Aero.), Aerodynamicist "B," Lockheed Aircraft Corp. (Burbank).

Carmody, James K., Engrg. Aide, Marquardt Aircraft Co.

Casteleiro, Carlos, B.S.M.E. (Aero.), Jr. Engr.—Aerodynamics, Performance Group, Convair (Ft. Worth).

Chabot, William J., Student, California Polytechnic Institute.

Chandler, Robert L., B.S. in Ae.E., Student & Engr., Chrysler Institute of Engineering, Chrysler Corp.

Clay, James T., B.S., 2nd Lt., USAF; Proj. Engr., Bomber Devel. Sect., Design Br., Aircraft Lab., WADC.

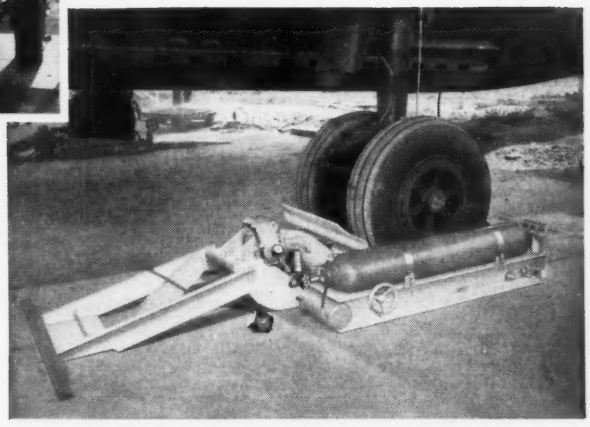
Dearing, E. F., Jr., B.S. in Ae.E., Assoc. Aircraft Engr. (Stress Analyst), Lockheed Aircraft Corp. (Marietta).

Dieckman, Earl J., Jr. Engr.—Design, Northrop Aircraft, Inc.

Docken, Richard G., Masters (Equiv.), Lt., USAF; Transonic Proj. Engr., WADC, Wright-Patterson AFB.

Dodge, Kenneth D., Weight Analyst, Northrop Aircraft, Inc.

Doerr, Frank J., B.S. in Ae.E., Jr. Engr. (Aerodynamics), McDonnell Aircraft Corp.



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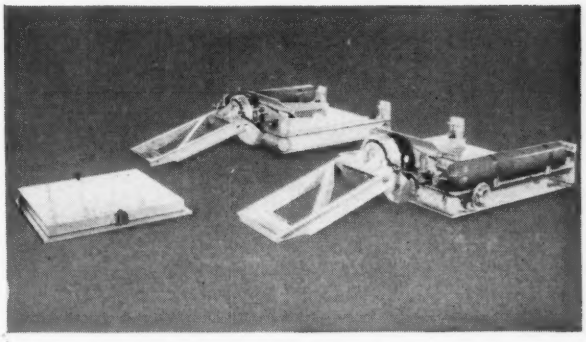

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Edelbaum, Theodore N., B. of Ae.E., Engr., Research Div., United Aircraft Corp.

Fenwick, James R., Jr. Design Engr.—Propulsion, North American Aviation, Inc. (Downey).

Ferguson, William L., Jr. Engr., Design Gr.–Power Plant, Cessna Aircraft Co.

Fisher, John N., Assoc. Engr., Lockheed Aircraft Corp. (Burbank).

Forbush, Jay M., Jr. Engr.—Aerodynamics, Ryan Aeronautical Co.

Gates, Chester W., Jr., A.E., Lt. Comdr., USN.

Glynn, William J., Major Layout Draftsman, North American Aviation, Inc. (Downey).

Golden, Lawrence E., S.B. & S.M. in Ae.E., 2nd Lt., USAF; Engrg. Proj. Officer (Kirtland AFB).

Gourdine, Meredith C., B.S. in Engrg. Physics, Ens., USN; Electronics Repair Officer, USS Coral Sea (CVA-43).

Grigg, Frederick H., B.S. in Ae.E.

Groesbeck, Donald E., B.S.E. (Aero.), Aero. Research Intern, NACA (Cleveland).

Gross, Lloyd Winslow, M.S. in Ae.E., Research Analyst "A," Northrop Aircraft, Inc. (Hawthorne).

Grove, William C., B.S.M.E. (Aero.), Associate Design Engr., Lockheed Aircraft Corp. (Burbank).

Gustainis, John, Jr., B.S. in Ae.E.

Harkins, William D., B.S. in Ae.E., Lt., USN.

Heinz, Richard A., B.S. in Ae.E., Exp. Test Engr., Pratt & Whitney Aircraft Div., United Aircraft Corp.

Herbel, Robert L., B.S., Aerodynamicist, Chance Vought Aircraft, Inc. (Dallas).

Heyman, Arthur, B. of Ae.E., Graduate Student, California Institute of Technology.

Hitchcock, Carl O., B. of Ae.E., Aerodynamicist "B," McDonnell Aircraft Corp.

Hochman, Harvey, B. of Ae.E., Ens., USNR.

Hunter, Aldridge T., Jr., B.S. in Ae.E., Proj. Officer, 4925 Test Group, Air Force Special Weapons Center (Kirtland AFB).

Hunter, Robert E., A.E., Jr. Scientist & Engr., Wright-Patterson AFB.

Jefferson, Kay Duane, M.S. in Ae.E., Lt., USAF; Asst. Research Staff Engr., OSR, ARDC (Pasadena).

Kaldobsky, P. R., B. of Ae.E., Devel. & Test Engr., Engrg. Div., Chrysler Corp.

Kaplan, Abner, Ph.D. in Ae.E., Research Engr. "A," Northrop Aircraft, Inc.

Kauffman, Roger H., B.S.M.E. & Ae.E., Engrg. Draftsman, Republic Aviation Corp.

Kita, Richard E., Pvt., USA; Draftsman, 141st Armd. Signal Co., 1st Armored Div. (Ft. Hood).

Korkegi, Robert H., Ph.D. in Aero., Research Assoc., Engrg. Center, University of Southern California.

Krout, Elwood L., B.S. in Ae.E., Asst. Design Engr., Pratt & Whitney Aircraft Div., United Aircraft Corp.

Kurit, Herbert, B.S.M.E., Research Engr., Hughes Aircraft Co.

Lanflisi, Raymond R., M.S. Ae.E., Aerodynamicist, Convair (San Diego).

Marrone, Paul V., B.S. in Ae.E., Research Asst. & Candidate for M.S. in Ae.E., Princeton Univ.

Matra, John P., Jr., B.S. (Aero.), Assoc. Engr., The Glenn L. Martin Co.

Matranga, Gene J., B.S. in M.E. (Aero.), Aerodynamic Research Intern, NACA (Edwards).

McCormick, Jack E., B.S.M.E. (Aero.), Prelim. Design Engr. "A," Boeing Airplane Co. (Seattle).

McWithey, Robert Richard, B.S.E. (Ae.E.), Aero. Research Intern, NACA (Langley Field).

Mehegan, Paul F., B.S., Jr. Research Engr., North American Aviation, Inc. (Los Angeles).

Myers, James R., B. of Ae.E., Engr., ARO, Inc.

Opatowsky, Stanley, B. of Ae.E., Flight Research Engr., Sikorsky Aircraft Div., United Aircraft Corp.

Pastoral, John G., B. of Ae.E., Jr. Engr., Grumman Aircraft Engineering Corp.

Pinkel, George E., B.S.

Rains, Dean A., Ph.D., Aerodynamicist, Propulsion Research Co.

(*Continued on page 136*)

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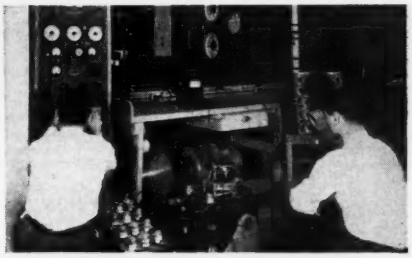
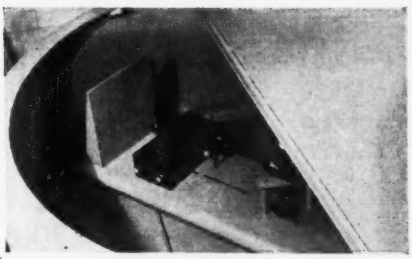


VIBRATION. Operational accuracy guaranteed at 5g from 20 to 55cps and at 10g from 55 to 225cps.



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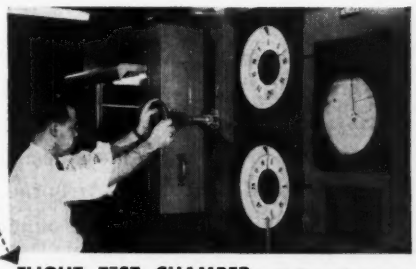

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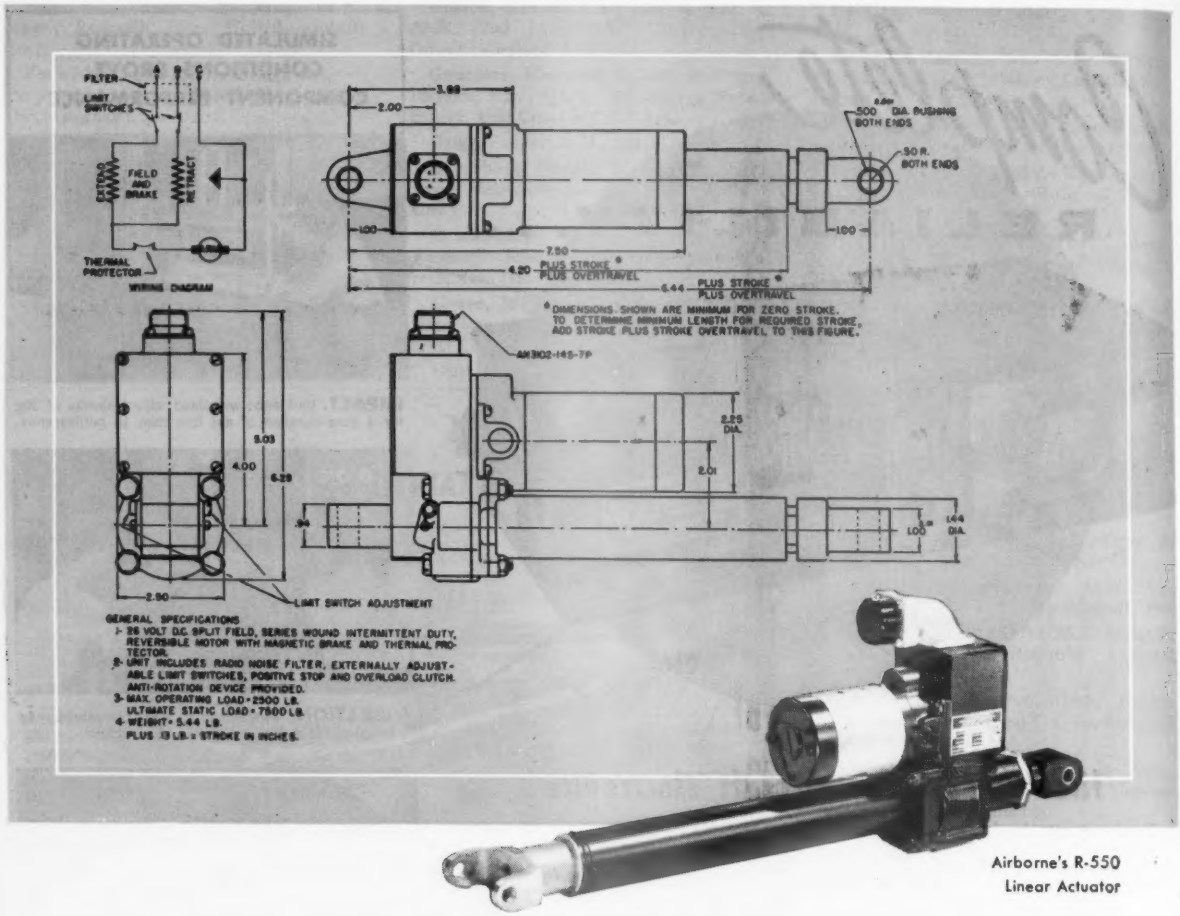
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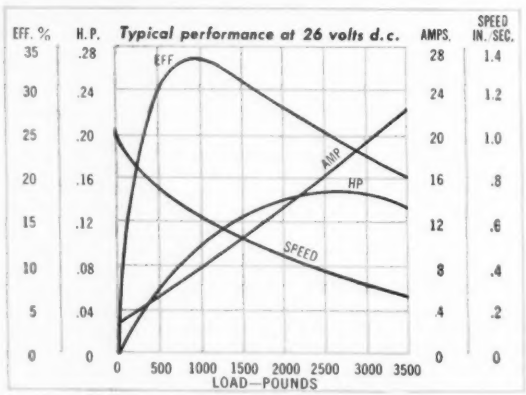

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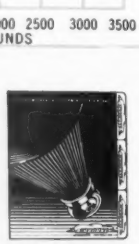

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Aerodynamics

L'Avion Aile Delta. R. Badie. *Tech. et Sci. Aéronautiques*, No. 3, 1953, p. 182. In French. Study of performance and aerodynamic characteristics of the delta-wing aircraft at supersonic and transonic speeds, including factors of longitudinal and lateral stability and control.

Les Essais de Vrille à la Soufferie Verticale de Lille. André Martinot-Lagarde. **Questionnaire sur la Vrille.** Jean Gobeltz. *Tech. et Sci. Aéronautiques*, No. 3, 1953, pp. 196, 202. In French. Experimental tests at the Lille Inst. of Fluid Mechanics in a vertical wind tunnel to determine the characteristics of the spin.

Theoretical Investigation of Longitudinal Response Characteristics of a Swept-Wing Fighter Airplane Having a Normal-Acceleration Control System and a Comparison with Other Types of Systems. Fred H. Stokes and Charles W. Mathews. *U.S., NACA TN 3191*, July, 1954. 50 pp.

Boundary Layer & Thermoaerodynamics

Direct Measurements of Skin Friction. Satish Dhawan. (*U.S., NACA TN 2567*, 1952.) *U.S., NACA Rep. 1121*, 1953. 20 pp. 26 refs. Supt. of Doc., Wash. $0.25. Design and construction of a device to measure local skin friction by determining the force exerted upon a very small movable part of the surface of the flat plate.

Evaporation from the Surface of a Body in an Airstream (With Particular Reference to the Chemical Method of Indicating Boundary-layer Transition). P. R. Owen and A. O. Ormerod. *Gt. Brit., ARC R&M 2875* (Sept., 1951), 1954. 42 pp. 28 refs. BIS, New York. $2.85.

Experimental Investigation of Temperature Recovery Factors on a 10° Cone at Angle of Attack at a Mach Number of 3.12. John R. Jack and Barry Moskowitz. *U.S., NACA TN 3256*, July, 1954. 15 pp.

Further Solutions of the Falkner-Skan Equation. K. Stewartson. *Proc. Cambridge Philos. Soc.*, July, 1954, p. 454. Investigation of the mechanism of flow separation of incompressible boundary layers.

Heat, Mass, and Momentum Transfer for Flow over a Flat Plate with Blowing or Suction. H. S. Mickley, R. C. Ross, A. L. Squyers, and W. E. Stewart. *U.S., NACA TN 3208*, July, 1954. 149 pp. 29 refs. Theoretical and experimental investigation at MIT of the effect on the boundary layer of sucking or blowing air through porous plate surfaces, with detailed charts, tables, and diagrams.

The Influence of Surface Waves on the Stability of a Laminar Boundary Layer with Uniform Suction. D. A. Spence and D. G. Randall. *Gt. Brit., ARC CP 161* (Mar., 1953), 1954. 29 pp. BIS, New York. $0.65.

On a Simple Method for Calculating Laminar Boundary Layers. K. E. G. Wieghardt. *Aero. Quart.*, May, 1954, p. 25. 17 refs.

Some Examples of Three-Dimensional Effects in Boundary Layer Flow. J. Wilkinson. *Aero. Quart.*, May, 1954, p. 73.

Stability of Compressible Laminar Boundary Layer with Internal Heat Sources or Sinks. George M. Low. *IAS Annual Summer Meeting, Los Angeles, June 21–24, 1954, Preprint 486*. 15 pp. Members, $0.50; nonmembers, $0.85.

Tabulation of the Blasius Function with Blowing and Suction. H. W. Emmons and D. C. Leigh. *Gt. Brit., ARC CP 157* (June 5, 1953), 1954. 81 pp. BIS, New York. $1.60.

On Calculating Incompressible Turbulent Boundary Layers with Arbitrary Pressure Distribution. H. Schuh. *Stockholm, KTH Aero TN 41*, Mar. 29, 1954. 23 pp. 17 refs.

Characteristics of Turbulence in a Boundary Layer with Zero Pressure Gradient. P. S. Klebanoff. *U.S., NACA TN 3178*, July, 1954. 56 pp. 20 refs.

Premières Mesures de Corrélations dans le Temps et l'Espace, dans la Couche Limite d'une Plaque Plane. A. Favre, J. Gaviglio, and R. Dumas. *La Recherche Aéronautique*, May–June, 1954, p. 27. In French. Experimental measurements of turbulent plane boundary layers with correlations of the data in time and space.

The Problem of the Turbulent Boundary Layer. Donald Coles. *ZAMP*, May 15, 1954, p. 181. 27 refs. Study of compressible boundary layers in steady two-dimensional mean flow past a smooth flat plate at sufficiently large Reynolds Numbers in order that the boundary-layer hypothesis may be applied under the assumptions that there is no heat transfer between the plate and the fluid and that the pressure, density, and velocity of the external flow are uniform.

Die turbulente Strömung an einer angeblasenen rotierenden Scheibe. E. Truckenbrodt. *ZAMM*, Apr.–May, 1954, p. 150. In German. Analysis of the turbulent boundary layer at the surface of a rotating disc in a stream parallel to the axis of rotation, with the thickness of the boundary layer and of the moment of the rotating disc dependent upon the ratio of the velocity of the axial flow to the peripheral velocity of the disc.

Control Surfaces

Changes in Control Characteristics with Changes in Flow Pattern at High Subsonic Speeds. Tests on an EC. 1250 Aerofoil with 25 per cent Concave Control Flap. I—Initial Observations. II—Repeat Tests with Turbulence. R. A. Shaw. *Gt. Brit., ARC R&M 2436* (Apr., 1949), 1954. 32 pp. BIS, New York. $1.90.

Further Experiments on an NACA 23031 Aerofoil with a 15 per cent Handley Page Slotted Flap in the Compressed Air Tunnel. R. Jones and A. H. Bell. *Gt. Brit., ARC R&M 2519* (Aug. 7, 1946), 1954. 16 pp. BIS, New York. $1.15.

Fluid Mechanics & Aerodynamic Theory

Effects of Surface Tension and Viscosity on Taylor Instability. Richard Bellman and Ralph H. Pennington. *Quart. Appl. Math.*, July, 1954, p. 151. For the case of two incompressible fluids of infinite depth, with the interface initially in the form of a sine wave with amplitude small compared to wave length, using the linear terms of hydrodynamic equations for the analysis.

Instability of Liquid Surfaces and the Formation of Drops. Joseph B. Keller and Ignace Kolodner. *J. Appl. Phys.*, July, 1954, p. 918. Extension of Taylor's theory to take into account surface tension and to determine the most unstable mode.

On a Generalization of Synge's Criterion for Sufficient Stability of Plane Parallel Flows. S. I. Pai. *Quart. Appl. Math.*, July, 1954, p. 203. For the case of the problem of velocity profiles with point of inflection and with either finite or infinite boundary condition.

Linearization of the Equations of Non-Steady Flow in a Compressible Fluid. John W. Miles. *J. Math. & Phys.*, July, 1954, p. 135. 16 refs. Extension of the analysis by Lin, Reissner, and Tsien to three-dimensional planar bodies with the boundary condition at infinity.

A Quantum Theory for Non-Viscous Fluids in the Lagrange Variables. S. F. B. Tyabji. *Proc. Cambridge Philos. Soc.*, July, 1954, p. 449.

Wave Motions and the Aerodynamic Drag on a Free Oil Surface. J. R. D. Francis. *Philos. Mag.* (*7th Ser.*), July, 1954, p. 695.

An Experimental Investigation of the Pressure Distribution on Five Bodies of Revolution at Mach Numbers of 2.45 and 3.19. G. B. Marson, R. E. Keates, and W. Socha. *Coll. of Aeronautics, Cranfield, Rep. 79*, Apr., 1954. 31 pp.

Hypersonic Similarity and the Tangent-Cone Approximation for Unyawed Bodies of Revolution. Ronald F. Probstein and Kenneth N. C. Bray. *Princeton U. Dept. Aero. Eng. Rep. 262*, May, 1954. 12 pp. 19 refs.

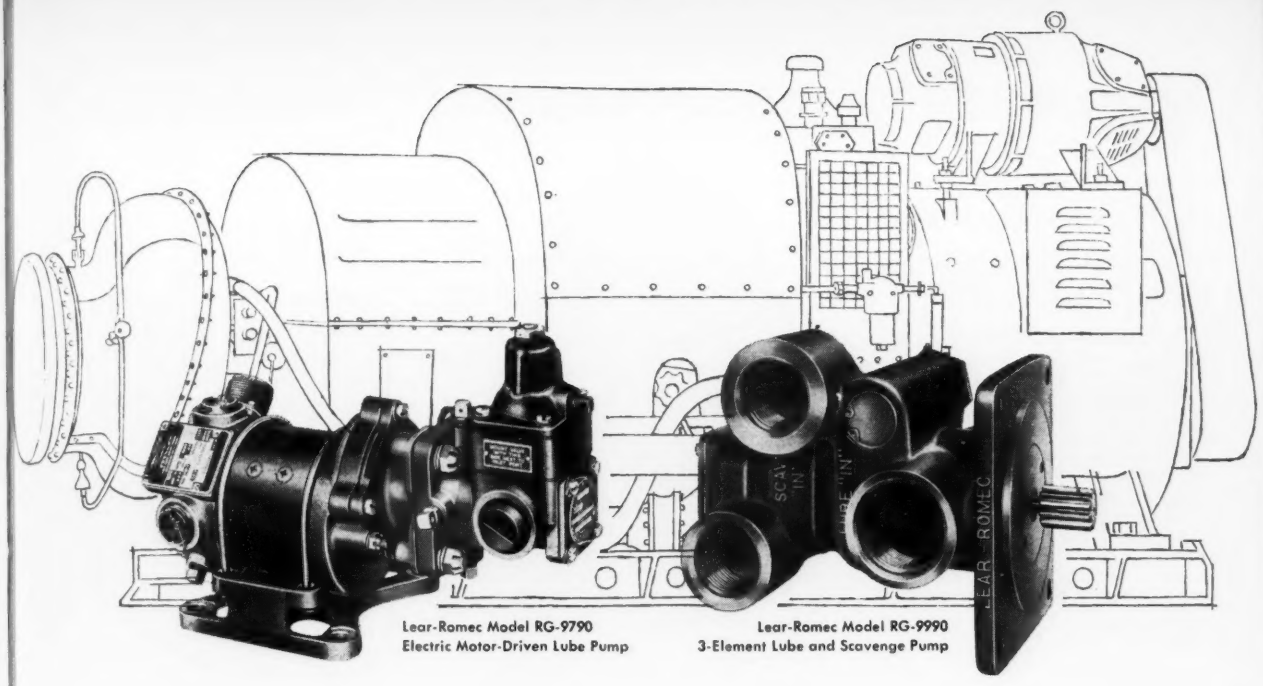
Theoretical Investigation at Subsonic Speeds of the Flow Ahead of a Slender Inclined Parabolic-Arc Body of Revolution and Correlation with Experimental Data Obtained at Low Speeds. William Letko and Edward C. B. Danforth, III. *U. S., NACA TN 3205*, July, 1954. 56 pp.

Effects of Wire Length in Turbulence Investigations with a Hot-Wire Anemometer. F. N. Frenkiel. *Aero. Quart.*, May, 1954, p. 1. 10 refs. NAVORD-supported study of the characteristics of the flow-measuring apparatus, with special attention to problems of length correction as related to the intensity of turbulence, correlation coefficients, and scales of turbulence.

The Diffusion Behind a Line Source in Homogeneous Turbulence. A. A. Townsend. *Proc. Royal Soc.* (*London*), *Ser. A*, July 22, 1954, p. 487. 11 refs. Experimental investigation to study the rate of lateral spread of the heat wake and of the possible interaction between the turbulent motion and the molecular conduction.

The Generalized Shock-Expansion Method and Its Application to Bodies Traveling at High Supersonic Airspeeds. A. J. Eggers, Jr., R. C. Savin, and C. A. Syvertson. *IAS Annual Summer Meeting, Los Angeles, June 21–24, 1954, Preprint 487*. 15 pp. 17 refs. Members, $0.50; nonmembers, $0.85.

Influence des Accélérations sur la Courbure des Chocs. I—Écoulements de Révolution. II—Écoulements Plans. Henri Cabannes. *La Recherche Aéronautique*, May–June, 1954, p. 3. In French. Analysis of the influence of accelerations on the curvature of shock



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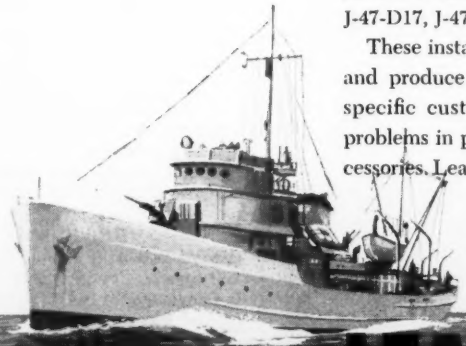

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waves attached to an obstacle in a compressible fluid at rest, and of the behavior of the phenomenon of the attachment and detachment of the shock waves for the cases of flows of revolution and of plane flows.

Shock-Turbulence Interaction and the Generation of Noise. H. S. Ribner. *U. S., NACA TN 3255*, July, 1954. 60 pp. 14 refs.

Metodi Grafici per lo Studio dei Moti Supersonici Piani (Graphical Methods for Studying Two-Dimensional Supersonic Flows). Aldo Muggia. *L'Aerotecnica*, Apr., 1954, p. 72. In Italian. Includes a method for the rapid solution of shock-wave problems.

The Numerical Solution of Certain Nonlinear Supersonic Flow Problems on the I.B.M. Card Programmed Calculator. J. H. Higman and R. E. Bower. *Grumman Aircraft Eng. Corp. Res. Dept. Rep. RE-67*, Oct. 15, 1953. 162 pp. 11 refs.

On a Perturbation Theory Based on the Method of Characteristics. C. C. Lin. *J. Math. & Phys.*, July, 1954, p. 117. 13 refs. Application to problems of supersonic flow.

An Outline of Supersonics. W. F. Hilton. *Aeronautics*, July, 1954, p. 50. Appraisal of certain fundamental aerodynamic principles, with emphasis on supersonic flow problems.

Transonic Limits of Linearized Theory. J. D. Cole. *IAS Annual Summer Meeting, Los Angeles, June 21–24, 1954, Preprint 485.* 10 pp. Members, $0.35; nonmembers, $0.75. Analysis of the relationship between the transonic and linearized theories, with quantitative estimate of the nonlinear effects in several cases including applications of unsteady motion.

Internal Flow

Ballistics of an Evaporation Droplet. C. C. Miesse. (*IAS–ARS Jt. Meeting, New York, Jan. 30, 1954, Paper.*) *Jet Propulsion*, July–Aug., 1954, p. 237. NavBuAer-sponsored investigation to determine the relationships between initial droplet and air velocities, initial and final droplet diameters, physical properties of the droplet and of the surrounding air, and the dimensions of the chamber; application to problems of upstream injection in a ramjet burner, spray-drying with counter current air flow, and impingement-type spray collectors.

An Experimental and Theoretical Investigation of Two-Dimensional Centrifugal-Pump Impellers. A. J. Acosta. *Trans. ASME*, July, 1954, p. 749. 14 refs. ONR-supported study to determine the usefulness of potential theory to describe the flow characteristics.

Heat Transfer and Fluid Friction During Flow Across Banks of Tubes. V—A Study of a Cylindrical Baffled Exchanger Without Internal Leakage. O. P. Bergelin, G. A. Brown, and A. P. Colburn. *Trans. ASME*, July, 1954, p. 841; Discussion, p. 849.

Influence d'une Rugosité Artificielle sur la Convection et la Frottement. E. Fournel and J. Génot. *La Recherche Aéronautique*, May–June, 1954, p. 31. In French. Experimental study of the influence of artificial roughness on turbulent convection and friction of air in a rectangular conduit.

Precipitation Tests on Aerosols. Jose Piazza. (*An. Soc. Cientifica* [Argentina], Feb., 1944, p. 49.) *Gt. Brit., MOS TIB T4300*, May, 1954. 25 pp. Translation. Investigation of conditions of dragging and precipitation of the liquid or solid particles dispersed in the gaseous phase as in stator or rotor devices in which a very active surface of contact is created between liquid-gas or solid-gas systems.

A Theoretical and Experimental Study of Finite Amplitude Wave Interactions with Channels of Varying Area. A. Kahane, W. R. Warren, W. C. Griffith, and A. A. Marino. *J. Aero. Sci.*, Aug., 1954, p. 502. 16 refs. ONR-sponsored investigation at Princeton U.; includes development of a one-dimensional graphical method to obtain the steady-state conditions after passage of an isentropic wave without necessity of previously required iterative procedures.

Wings & Airfoils

Aileron Reversal and Wing Divergence of Swept Wings. Appendix I—The Flexural Modes of Distortion and Iterative Treatment. Appendix II—Semi-rigid solution for General Modes. E. G. Broadbent and Ola Mansfield. *Gt. Brit., ARC R&M 2817* (Sept., 1947), 1954. 26 pp. 13 refs. BIS, New York. $1.70.

Ailes à Queue d'Hirondelle; Équilibrage des Moments. A. Buret. *Tech. et Sci. Aéronautiques*, No. 3, 1953, p. 188. In French. Characteristics of swallow-tail wings; analysis of the balancing of aerodynamic moments of wings of marked sweep and small aspect ratio at high altitude and at high speeds.

Caractéristiques Aérodynamiques Théoriques des Ailes Delta et des Ailes en Queue d'Hirondelle pour M < 3,5. Claude Picard. **Annexe—Note sur le Calcul de la Position du Centre de Poussée d'Ailes en Queue d'Hirondelle en Transsonique.** P. Bévierre. *La Recherche Aéronautique*, May–June, 1954, pp. 15, 26. 17 refs. In French. Theoretical aerodynamic characteristics of delta and swallow-tail wings with swept-back leading edges of between 45° and 75° studied at Mach Numbers 0–3.5.

The Delta Wing in a Non-Uniform Supersonic Stream. G. N. Lance. *Aero. Quart.*, May, 1954, p. 55. 18 refs.

Experimental Investigation of Influence of Edge Shape on the Aerodynamic Characteristics of Low-Aspect-Ratio Wings at Low Speeds. G. E. Bartlett and R. J. Vidal. (*Cornell Aero. Lab. Rep. 62*, 1954). *IAS Annual Summer Meeting, Los Angeles, June 21–24, 1954, Preprint 491.* 59 pp. 30 refs.

An Experimental Study of the Lift and Pressure Distribution on a Double-Wedge Profile at Mach Numbers Near Shock Attachment. Walter G. Vincenti, Duane W. Dugan, and E. Ray Phelps. *U.S., NACA TN 3225*, July, 1954. 43 pp. 37 refs.

Lift and Pitching Moment at Supersonic Speeds Due to Constant Vertical Acceleration for Thin Sweptback Tapered Wings with Streamwise Tips; Supersonic Leading and Trailing Edges. Isabella J. Cole and Kenneth Margolis. *U.S., NACA TN 3196*, July, 1954. 67 pp. 16 refs.

Notes on the Induced Drag of a Wing-Tail Combination. C. H. Naylor. *Gt. Brit., ARC R&M 2528* (July, 1946), 1954. 10 pp. BIS, New York. $0.75.

Study of the Subsonic Forces and Moments on an Inclined Plate of Infinite Span. Bradford H. Wick. *U.S., NACA TN 3221*, June, 1954. 25 pp. 10 refs.

Théorie des Corps Élancés. E. A. Eichelbrenner. *France, ONERA Pub. 68*, 1954. 75 pp. 11 refs. In French. Generalization of the theories of Jones, Legendre, von Baranoff, Ward, Mac Adams, and Sears covering slender bodies to the case of wings in turbulent flow influencing the potential distribution of aerodynamic forces as in the swallow-tail design.

Theory of an Accelerated Slender Supersonic Aerofoil. Geoffrey L. Sewell. *Aero. Quart.*, May, 1954, p. 52. Solution of the problem by a perturbation method taking into account the effect of the acceleration of the form of the shock line for cases of small acceleration.

Aeroelasticity

Cascade Blade Flutter and Wake Excitation. J. F. W. Parry and H. Pearson. *J. RAeS*, July, 1954, p. 505.

Essais de Flutter dans la Zone Sonique sur Maquettes Larguées en Chute Libre. R. Dat, R. Destuynder, H. Loiseau, and H. Trubert. *La Recherche Aéronautique*, May–June, 1954, p. 39. In French. Experimental flutter tests, in the sonic region using models released in free fall to measure critical speeds of swept-back wings.

Influence de l'Amortissement Interne sur les Caractéristiques Vibratoires des Avions. G. de Vries. *La Recherche Aéronautique*, May–June, 1954, p. 35. In French. Study of the effects of internal damping on the vibrational characteristics of an aircraft.

Notes on the Dynamic Response of an Aircraft to Gusts and on the Variation of Gust Velocity along the Flight Path, With Special Reference to Measurements made in Lancaster P.D. 119. Anne Burns. *Gt. Brit., ARC R&M 2759* (Sept., 1949), 1954. 18 pp. BIS, New York. $1.70.

Resonance Amplitudes In Systems With a Single Degree of Freedom. H. Norman Abramson. *Prod. Eng.*, Aug., 1954, p. 179. Review of the linear theory with a solution of a general nonlinear system taking into account both restoring and damping factors.

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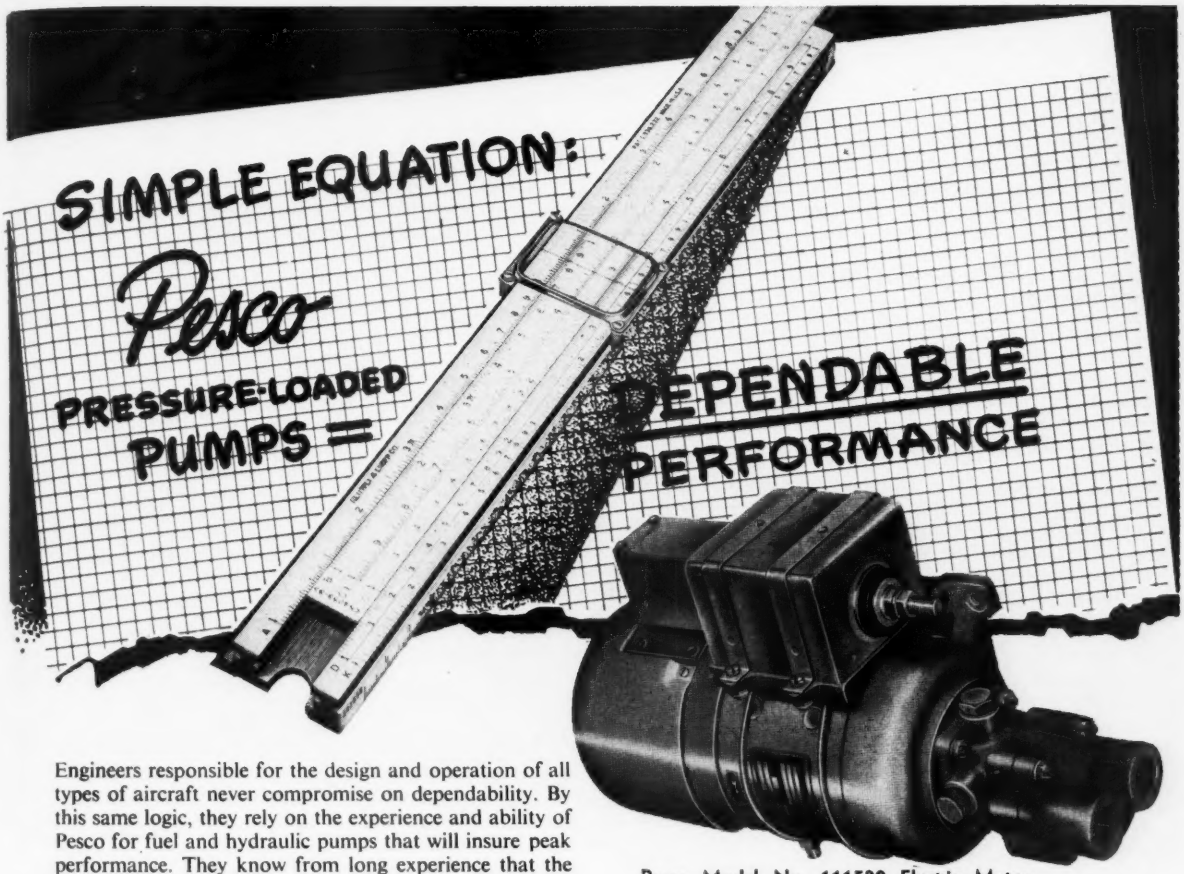

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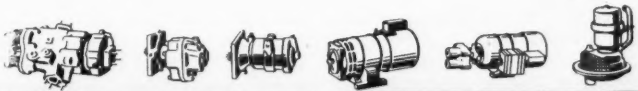

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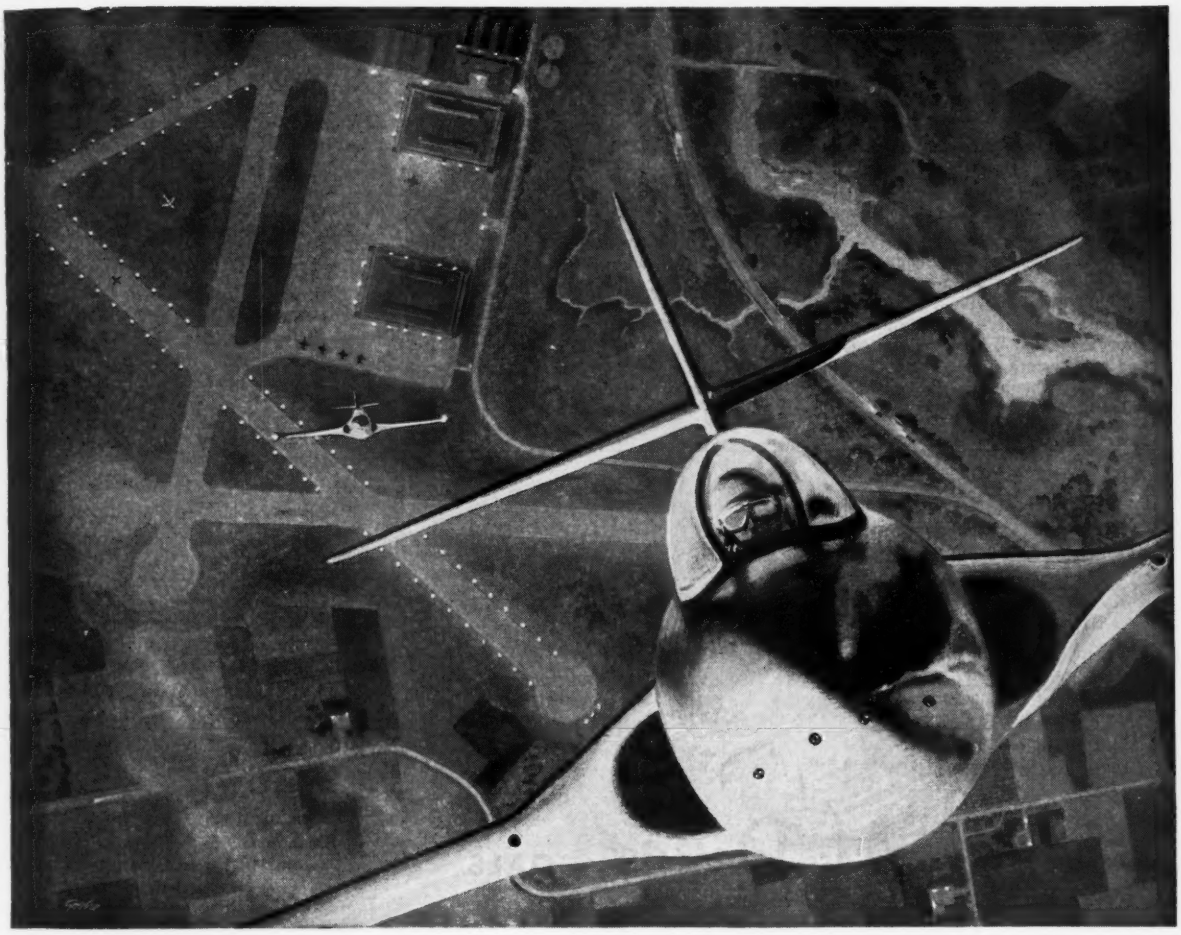

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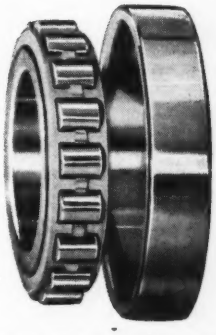

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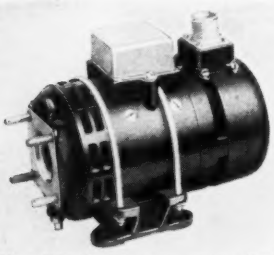

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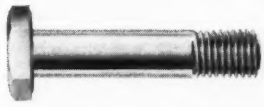

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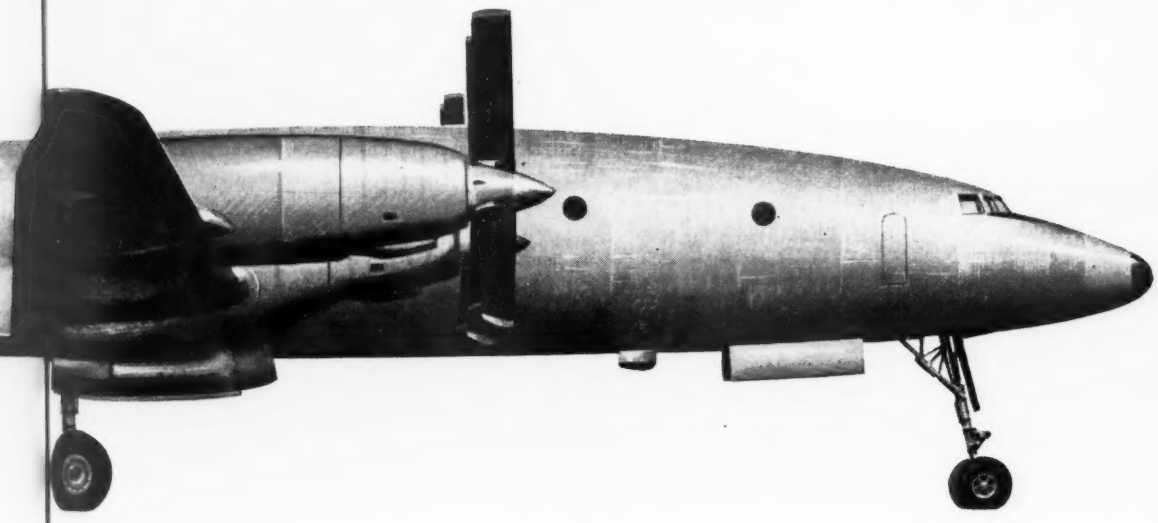

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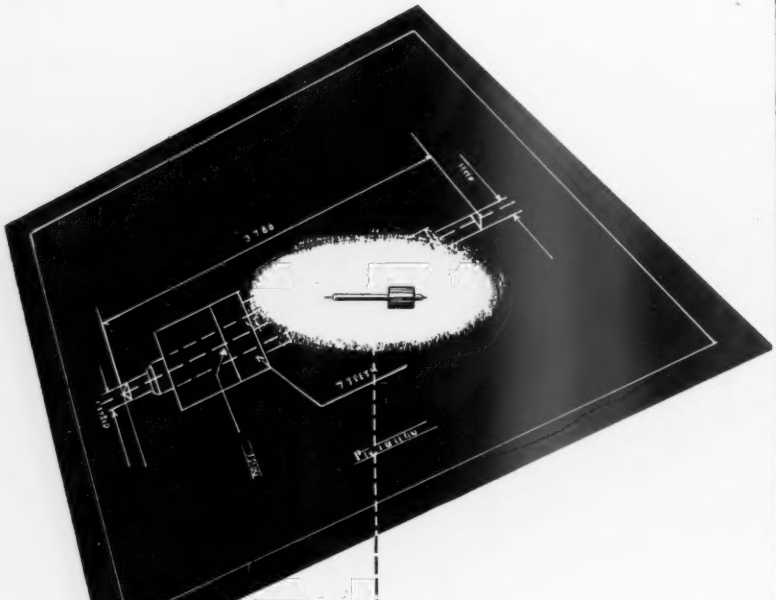

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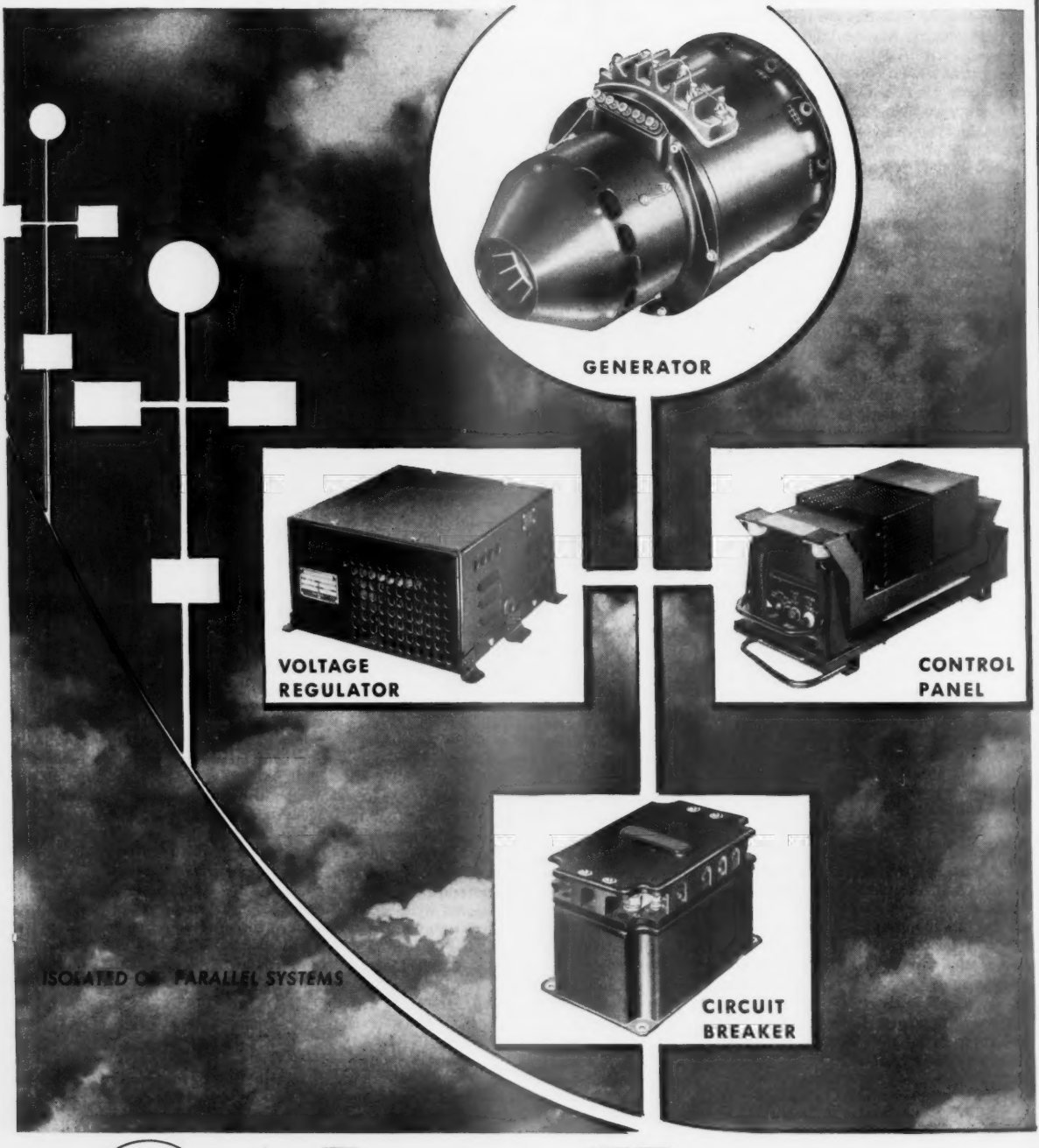

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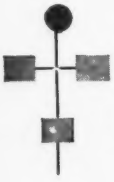

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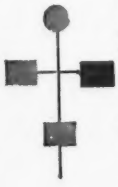

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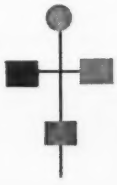

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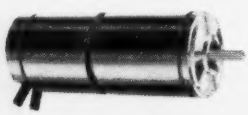

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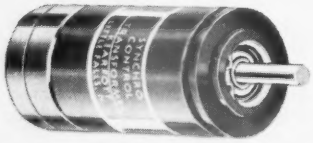

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The Propagation of Longitudinal Elastic Waves along Cylindrical Bars. H. Kolsky. *Philos. Mag.* (*7th Ser.*), July, 1954, p. 712. 23 refs.

Experimental Stress Analysis of Stiffened Cylinders with Cutouts, Shear Load. Floyd R. Schlechte and Richard Rosecrans. *U.S., NACA TN 3192*, July 1954. 87 pp.

A Note on Second-Order Effects in the Torsion of Incompressible Cylinders. A. E. Green. *Proc. Cambridge Philos. Soc.*, July, 1954, p. 488.

On the Timoshenko Theory of Transverse Beam Vibrations. C. L. Dolph. *Quart. Appl. Math.*, July, 1954, p. 175. 11 refs.

The Significance of the Tension Test for Spot Welds. E. R. Funk. *Welding J. Res. Suppl.*, July, 1954, p. 363-s.

Test Development of Structures Designed Understrength. John H. Meyer. *IAS Annual Summer Meeting, Los Angeles, June 21–24, 1954, Preprint 470.* 23 pp. Members, $0.65; nonmembers, $1.00.

Elasticity & Plasticity

New Methods in the Analysis and Design of Structures in the Plastic Range. J. F. Baker and M. R. Horne. *Brit. Welding J.*, July, 1954, p. 307. 10 refs. Techniques of design and of plastic-moment distribution based on an analogy between the conditions governing structural behavior as related to the idea of plastic hinges and the equivalent conditions for the elastic range.

On the Concept of Stability of Inelastic Systems. D. C. Drucker and E T. Onat. *J. Aero. Sci.*, Aug., 1954, p. 543. Use of simple models to bring out large and important differences between buckling in the plastic range and classical elastic instability, with a comparative appraisal of nonlinear static and kinetic criteria and their interrelationships.

Over het Knikvraagstuk in het Plastische Gebied bij Staven en Platen (On the Buckling of Rods and Plates in the Plastic Region). II. J. P. Benthem. *Netherlands, NLL Rep. S. 423*, Jan., 1954. 56 pp. 48 refs. In Dutch.

Second-Order Effects in the Deformation of Elastic Bodies. A. E. Green and E. B. Spratt. *Proc. Royal Soc.* (*London*), *Ser. A*, July 7, 1954, p. 347. 11 refs. Development of a systematic theory of successive approximation for both compressible and incompressible bodies using general tensor notations.

Stress Functions of Maxwell and Morera. Wilhelm Ornstein. *Quart. Appl. Math.*, July, 1954, p. 198. Application to elasticity problems of structural analyses.

Plates

Buckling of Oblique Plates with Clamped Edges Under Uniform Shear. W. H. Wittrick. *Aero. Quart.*, May 1954, p. 39.

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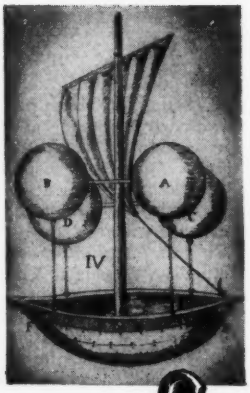

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Calculating the Area of Curved Surfaces. Victor Tatarinov. *Prod. Eng.*, Aug., 1954, p. 201. A graphical and analytical method applicable to the design of curved plates and sheets.

Flexure-Torsion Failure of Panels; A Study of Instability and Failure of Stiffened Panels under Compression when Buckling in Long Wavelengths. II. John H. Argyris. *Aircraft Engr.*, July, 1954, p. 213.

Singularly Loaded Rectilinear Plates. I. B. D. Aggarwala. *ZAMM*, June, 1954, p. 226. 12 refs. Use of a vortex analogy to calculate the deflection and the shearing forces of the plates under concentrated loads.

The Static Stability of a Two-Dimensional Curved Panel in a Supersonic Flow, with an Application to Panel Flutter. Y. C. Fung. *J. Aero. Sci.*, Aug., 1954, p. 556. Analytical solution for the case of a panel hinged at two opposite edges with the distance between the hinges held fixed, taking into account the variation of the panel shape with increasing dynamic pressure of the flow; application to the problems of thermal buckling.

Thermodynamics

Combustion

Determination of the Distribution of Some Parameters Across the Combustion Zone of a Flat Flame. J. H. Burgoyne and F. J. Weinberg. *Proc. Royal Soc. (London), Ser. A*, July 7, 1954, p. 286.

Fluid-Mechanical Aspects of Flame Stabilization. Lester Lees. *Jet Propulsion*, July–Aug., 1954, p. 234. Investigation of the problem for the case of fully premixed gas mixtures at Reynolds Numbers sufficiently high in order that the flow in the wake be fully turbulent.

On the Burning of Single Drops of Fuel in an Oxidizing Atmosphere. M. Goldsmith and S. S. Penner. *Jet Propulsion*, July–Aug., 1954, p. 245. 10 refs. Extension and generalization of Godsave's experimental investigation with the principal assumptions that the flame front is established at a spherical surface surrounding the drop, that the rates of delivery of fuel and oxygen to this surface are in stoichiometric proportions, and that the rates of reaction at the flame front are fast compared to the rates of delivery of combustible gases.

The Physical Structure of Turbulent Flames. Martin Summerfield, Sidney H. Reiter, Victor Kebely, and Richard W. Mascolo. *Jet Propulsion*, July–Aug., 1954, p. 254. 13 refs.

Heat Transfer

Evaluation of Transient Temperatures and Stresses. R. J. Fritz. *ASME Trans.*, Aug., 1954, p. 913. 29 refs. Analytical solutions to the one-dimensional, heat conduction equation for arbitrary surface temperature transients, with a determination of the maximum thermal stresses for a flat plate due to a given surface temperature change at a linear rate.

Measurement of the Viscosity of Five Gases at Elevated Pressures by the Oscil-

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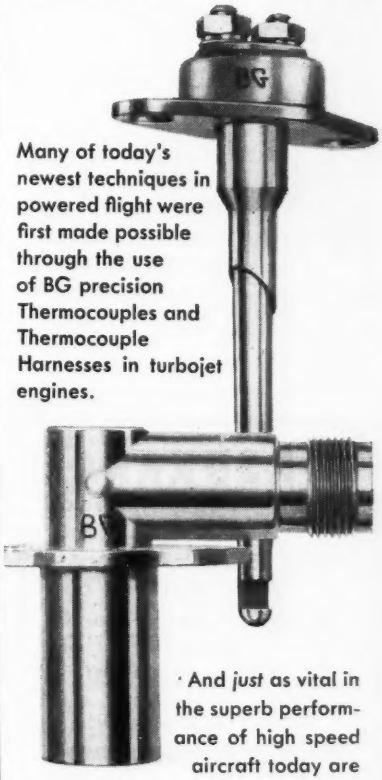

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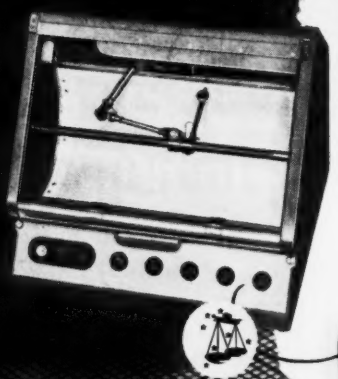

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lating-Disk Method. J. Kestin and K. Pilarczyk. *ASME Trans.*, Aug., 1954, p. 987. 48 refs. Experimental data to supplement the NBS-NACA Thermal Tables.

A Method of Measuring the Thermal Conductivity of Poor Conductors. L. N. Clarke. *Australian J. Appl. Sci.*, June, 1954, p. 178. Experimental development of a technique representing an intermediate stage between the steady-state and the transient methods.

On the Application of Ångstrom's Method of Measuring Thermal Conductivity. C. H. Bosanquet and R. Aris. *Brit. J. Appl. Phys.*, July, 1954, p. 252. Technique of calculation without a Fourier analysis of the steady periodic motion of heat along a bar.

A Study of the Effects of Cyclic Thermal Stresses on a Ductile Metal. L. F. Coffin, Jr. *ASME Trans.*, Aug., 1954, p. 931; Discussion, p. 949. 44 refs. Experimental investigation at G-E, with a comprehensive bibliography of the literature.

Apparatus for Study of Effects of Cyclic Thermal Stresses on Ductile Metals. L. F. Coffin, Jr., and R. P. Wesley. *ASME Trans.*, Aug., 1954, p. 923.

The Thermal Conductivity of Fluids. A. F. Schmidt and B. H. Spurlock, Jr. *Trans. ASME*, July, 1954, p. 823. 43 refs. Development of a compensating type hot-wire apparatus and method for measurements involving gases, vapors, and liquids over a wide range of temperatures.

Thermal Conductivity of Gases. F. G. Keyes. *Trans. ASME*, July, 1954, p. 809. 16 refs. Extension of USAF-ONR-Army-sponsored research under Project Squid into fundamental properties to be applied in the design of heat-transfer equipment; measurements include values for viscosity obtained by correlation of all available data in the literature.

The Thermal Conductivity of Some Organic Liquids. M. F. Dick and D. W. McCready. *Trans. ASME*, July, 1954, p. 831. USAF-supported study at U. of Mich. to design and construct a horizontal parallel-plate apparatus for conductivity measurements of 19 liquid organic compounds at 20° and 60°C.

Thermal Problems of High Performance Flight. David Rendel. (*Bristol Conf. on Thermal Stress, Jan. 8, 1954, Paper.*) *Aircraft Eng.*, July, 1954, p. 220. Analytical review of structural, aerodynamic, and other factors related to thermodynamic considerations.

The Viscosity, Thermal Conductivity, and Prandtl Number for Air, O_2, N_2, NO, H_2, CO, CO_2, H_2O, He, and A. Joseph Hilsenrath and Y. S. Touloukian. *ASME Trans.*, Aug., 1954, p. 967; Discussion, p. 983. 117 refs. NACA-sponsored comprehensive compilation and correlation of thermal data at NBS to study various gases for aerodynamic and other applications, with an extensive bibliography.

Über ein ebenes unstetiges Temperaturspannungsproblem. Max Hieke. *ZAMM*, Apr.–May, 1954, p. 9. In German. Determination of the thermal stresses in a cylinder of infinite length under the assumption of a discontinuous heat distribution.

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Aerodynamic Characteristics of a Refined Deep-Step Planing-Tail Flying-Boat Hull with Various Forebody and Afterbody Shapes. John M. Riebe and Rodger L. Naeseth. (*U.S., NACA TN 2489*, 1952.) *U.S., NACA Rep. 1144*, 1953. Supt. of Doc., Wash. $0.25.

A Hydrodynamic Study of the Chines-Dry Planing Body. John D. Pierson, David A. Dingee, and Joseph W. Neidinger. (*Stevens Inst. Tech. Exp. Towing Tank Rep. 492*, May, 1954.) *IAS Preprint FF-9*, 1954. 59 pp. 11 refs. Members, $1.20; nonmembers, $1.60. Development of an analogical theoretical method for determining pressure distributions and loads on prismatic Vee-shaped bodies planing at high speed.

On the Low Speed Maneuverability of Flying Boats on the Water. F. W. S. Locke, Jr. *U.S., NavBuAer RDR 1520*, May, 1954. 48 pp. 30 refs. Detailed analysis of flight test results covering performance characteristics in terms of design requirements.

A Review of Porpoising Instability of Seaplanes. Appendix I—Examination of Porpoising Characteristics of Particular Seaplanes. Appendix II—Theoretical Evidence. A. G. Smith and H. G. White. *Gt. Brit., ARC R&M 2852* (Feb., 1944), 1954. 41 pp. 44 refs. BIS, New York. $2.50.

Wind Tunnels & Research Facilities

Calibration of the R.A.E. No. 18 (9 in. × 9 in.) Supersonic Wind Tunnel. I—Preliminary Investigations. W. T. Lord and D. Beastall. II—Tests at Atmospheric Stagnation Pressure. W. T. Lord, G. K. Hunt, R. J. Pallant, and J. Turner. *Gt. Brit., ARC CP 162, 163* (Sept., 1953), 1954. 44, 24 pp. BIS, New York. $1.00, $0.65.

Considerations on a Large Hydraulic Jet Catapult. Upshur T. Joyner and Walter B. Horne. *U.S., NACA TN 3203*, July, 1954. 49 pp. Design and development of the research equipment featuring a jet nozzle and a test car, with performance data.

Development and Operation of the C.A.L. Perforated-Throat Transonic Wind Tunnel. Appendix A—Potential Flow Near a Wall with Periodically-Varying Boundary Conditions. Appendix B—Subsonic Flow in the Perforated-Wall Wind Tunnel. A. H. Flax, I. G. Ross, R. S. Kelso, and J. G. Wilder. *IAS Annual Summer Meeting, Los Angeles, June 21–24, 1954, Preprint 492*. 50 pp. 15 refs. USAF-NavBuAer-supported experimental investigation of design characteristics and potentialities; detailed analysis of performance and flow factors, with charts, tables, and diagrams.

Les Essais de Vrille à la Soufflerie Verticale de Lille. André Martinot-Lagarde. **Questionnaire sur la Vrille.** Jean Gobeltz. *Tech. et Sci. Aéronautiques*, No. 3, 1953, pp. 196, 202. In French. Experimental tests at the Lille Inst. of Fluid Mechanics in a vertical wind tunnel to determine the characteristics of the spin.

Misure nella Galleria a Vento in Moto Non Permanente (Wind Tunnel Measurements in Non Steady Flow). I. Ennio Mattioli. *L'Aerotecnica*, Apr., 1954, p. 83. In Italian. Design and construction of a hot-wire anemometer and of a strain-gage balance for wind tunnels.

A Possible Method for Obtaining High Mach Numbers using Compressed Air Supplies of Relative Low Pressures. F. van der Walle. *J. RAeS*, July, 1954, p. 510.

The Princeton Helium Hypersonic Tunnel and Preliminary Results Above M = 11. S. M. Bogdonoff and A. G. Hammitt. *Princeton U. Dept. Aero. Eng. Rep. 260*, June, 1954. 50 pp. 23 refs.

Progress in Supersonic Wind-Tunnel Design. Antonio Ferri. *Appl. Mech. Rev.*, Aug., 1954, p. 329. 29 refs. Survey of investigations of aerodynamic characteristics and of technical problems.

Special Progress Report, 1954: Aviation Research and Development. *Av. Age*, July, 1954. 304 pp. Includes comprehensive coverage on aerodynamics, aircraft, propulsion and power plants, aircraft construction, materials, aircraft systems and components, navigational aids, airports, test and research equipment, comfortization, and human engineering.

Transonic Wind Tunnel Development at the NACA Ames Aeronautical Laboratory. H. Julian Allen and Joseph M. Spiegel. *IAS Annual Summer Meeting, Los Angeles, June 21–24, 1954, Preprint 474*. 7 pp. Members, $0.35; nonmembers, $0.75.

Twin Drive Designed for New Transonic Wind Tunnel. M. F. Gay and Elroy Boening. *Allis-Chalmers Elec. Rev.*, 2nd Quarter, 1954, p. 10. Operational requirements and special equipment features of the Navy's David Taylor Model Basin Wind Tunnel.

IAS News, *Members Elected*

(*Continued from page 104*)

Reed, John Chase, M.S. in Ae.E., 1st Lt., USAF; Proj. Officer, 4925 Test Group (Atomic), Kirtland AFB.

Rose, Peter H., M. of Ae.E., Aerodynamicist, Douglas Aircraft Co., Inc. (Santa Monica).

Schoenberger, Murry, B.S. in Ae.E., Assoc. Engr.–Production Design Div., The Glenn L. Martin Co.

Shulenberger, M. K., B.S. in Ae.E.; B.S.M.E., Engr., Flight Test Sect., Operations Unit, Boeing Airplane Co. (Seattle).

Spears, Paul H., B.S. in Ae.E., Lt. Comdr., USN; Naval Aviator, NAS (San Diego).

Sweeney, Hugh J., B.S., Aero. Engr., Installation Engineering Dept., Pratt & Whitney Aircraft Div., United Aircraft Corp.

Thompson, Robert J., Draftsman, Reynolds Metals Co.

Tripp, Fay L., M. of Ae.E., Instr. in Aero. Engrg., Rensselaer Polytechnic Institute.

Wagner, Hart, B. of Ae.E., Aerodynamicist—Flight Test, Grumman Aircraft Engineering Corp.

Walker, John H., III, B.S., 2nd Lt., Student Officer–Pilot Training, USAF.

Wallace, G. A., Jr. Engr.–Flight Test Analysis, Lockheed Aircraft Corp. (Burbank).

Webb, Wilmont H., B. of Ae.E., Research Asst., Rensselaer Polytechnic Institute.

Weisman, Fred T., B.S.Ae.E., Jr. Engr., AGT Div., Westinghouse Electric Corp. (Kansas City).

Wilson, Emmette G., Jr. Engr., Flight Test Analysis, Chance Vought Aircraft, Inc.

Wizansky, Dan, B.A.E., Design Engr., Aero. Design & Engineering Co.

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The Atomization of Liquid Fuels

By E. Giffen and A. Murazew. New York, John Wiley and Sons, Inc., 1953. 246 pp., illus., diagrs. $6.00.

Whenever liquid fuel is used as a source of heat, as in a furnace, or as a source of mechanical energy, as in internal combustion engines, gas turbines, and jet engines, the fuel must be first atomized, i.e., broken up into small droplets, before combustion can take place. On the characteristics of atomization, that is, on the degree of fineness and evenness of the spray; and on its distribution in space and time, depends to a large degree the efficiency of combustion, hence the economy of fuel utilization.

A great deal of research work has been expended, and much still remains to be done, in order to clarify the physical phenomenon of atomization, and to assess the influence of the numerous variables of the fuel and the surrounding gas or air, on the properties of the spray, and to measure the significant properties, and thereby to give the practical problems of spray production a sound theoretical foundation. This is a difficult task because spray science comprises a number of disciplines, such as mathematics, physics, hydro- and aerodynamics, and mechanical engineering.

The book under review deals with the problems and methods of theoretical and experimental investigation of sprays. The authors, themselves meritorious contributors to this branch of science, have produced an authoritative and comprehensive treatise. There are ten chapters—comprising about 70 sections and subsections—arranged in a logical sequence; listing these will indicate the scope of the book:

Mechanism of disintegration of liquid jets; motion of small liquid drops in air; spray formation and penetration, energy of atomization, and a survey of spray formation theories.

Spray characteristics such as cone angle, dispersion, and size and uniformity of droplets.

Effect of atomizer design on flow in atomizer, spray penetration, and cone angle.

Theory of the swirl atomizer, air core, and cone angle.

Dimensional analysis applied to the correlation of atomization data.

Effect of physical properties of the liquid on spray dispersion, cone angle, velocity, and penetration.

Effect of the properties of the gaseous medium on the spray properties.

Effect of the injection pressure on spray penetration, cone angle, and droplet size.

Formation and development of intermittent and continuous sprays; variation of pressure and velocity; progressive development of atomization.

Experimental methods for the assessment of fuel spray characteristics, of velocity, penetration, cone angle, structure, dispersion, droplet size; use of substitute liquids for droplet measurement.

A list of about 100 references is included.

This is a well-balanced treatise, written in a lucid style, an excellent introduction and sound foundation for those concerned with atomized fuels.

Prof. K. J. DeJuhasz
Science and Engineering Consultant
U. S. Army, Europe

Luftfahrtversicherung unter besonderer Berücksichtigung der Luftpools

By Ernst A. Kubli. Zurich, Schultheiss & Co., A.G., 1952. 292 pp. Sw.fr. 16.—. (In German.)

The title of this thesis might be referred to in English as "Aviation Insurance, with Particular Reference to Aviation (Insurance) Pools." It was presented by the author, a Swiss, to the Faculty of Economics of the University of Zurich (Switzerland), in 1951, in order to obtain a doctor's degree in Economics.

The book represents a very thorough and comprehensive study of most problems connected with aviation insurance. Its contents cover the majority of those countries where aviation insurance has developed into an important class of insurance. This thesis is likewise of interest to the aviation insurance specialist, the economist as well as the student of aviation law.

The *first part* of the book contains a review of the general principles and the various lines of aviation insurance (aviation accident, aviation liability, aircraft hull) and their numerous subdivisions. The legislation governing aviation in general and aviation insurance in particular are discussed in a subsequent chapter. The author then analyzes the nature of the aviation hazard, the catastrophe exposure inherent in certain air risks and the consequences thereof for underwriting technique, ratemaking, etc. The last chapter of the thesis' first part includes a historical sketch of aviation insurance with regard to seven European countries (England, France, Germany, Scandinavia, Holland, Belgium, and Switzerland) and the United States of America.

In the *second and main part* of his study, Dr. Kubli analyzes the organization of the world's major aviation insurance markets. The specific nature of the aviation hazard and the largeness of certain risks seeking adequate insurance protection have led the insurers in most countries to adopt special group plans and establish aviation insurance groups or so-called "aviation pools" (Luftpools). These pooling arrangements are discussed in the first five chapters of the second part.

Each member company of an "aviation pool" usually has only a modest participation in any individual risk written through the pool, but all participations in the aggregate create the needed capacity for the insurance of the largest aviation risks. At the same time, the catastrophe hazard inherent in such risks is distributed economically and each of the member companies of the pool gains a much better spread of risks in this often very unbalanced line of insurance. The author describes in great detail the method by which the important

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spread of risks is arrived at under different group plans. The setup, the functions and activities of several European and American pools are also thoroughly examined, as are the legal problems arising out of such pooling arrangements, the effects on the competitive situation in the national insurance market, etc.

The last two chapters of the second part deal with the British and Belgian aviation insurance markets where so-called "specialist companies" (insuring aviation risks exclusively) and similarly specialized Lloyd's aviation syndicates have taken the place of "aviation pools."

The appendix to this very readable treatise includes an interesting review of the history, the objectives and the activities of the "International Union of Aviation Insurers."

Jerome Lederer
Director
Flight Safety Foundation, Inc.
Cornell-Guggenheim Aviation Safety Center

Book Notes

AERODYNAMICS

Essentials of Fluid Dynamics with Applications to Hydraulics, Aeronautics, Meteorology and Other Subjects. Ludwig Prandtl. New York, Hafner Publishing Company, 1952. 452 pp., illus., diagrs., figs., $6.

This book is a translation of the 1949 edition of *Führer durch die Strömungslehre*. The German title indicates that the book is intended to be a guide to the reader, to the beginner, and to the advanced student as well as to the expert in an adjoining field of research. Complex mathematical analysis has been avoided as far as possible, and in general formulas take second place, the principal hope being the awakening of clear, intuitive comprehension. Footnotes contain many references to original papers and textbooks for those readers who are already familiar with the problem of fluid dynamics and wish to refer to original sources in further detail. In order to complete the references to papers published in Great Britain and the United States during and after World War II, an appendix has been added listing these publications. This present work of Dr. Prandtl's is also available in a French edition which was published by Dunod, Paris, in 1952 under the title of *Guide à Travers la Mécanique des Fluides*.

Contents, Chapter I, Equilibrium of Liquids and Gases. Chapter II, Kinematics; Dynamics of Frictionless Fluids: 1. Kinematics; 2. Dynamics of Frictionless Fluid. Chapter III, Motion of Viscous Fluids; Turbulence; Fluid Resistance; Practical Applications. Chapter IV, Flow with Appreciable Volume Changes (Dynamics of Gases). Chapter V, Miscellaneous Topics: A. Combined Effects of More than One State of Matter. B. Rotating Body and Rotating System of Reference. C. Flow in Heavy Stratified Fluids. D. Heat Transfer in Moving Fluids; Cases of Flow due to Heat. Bibliography: Recent Works in Hydrodynamics. Appendix. List of Books in English, Notes and References to Recent Publications in English. Index.

Mémoires sur la Mécanique des Fluides Offerts à M. Dimitri P. Riabouchinsky par ses Amis, ses Collégues et ses Anciens Élèves à l'Occasion de son Jubilé Scientifique. Paris, Service de Documentation et D'Information Technique de L'Aeronautique, 1954. 441 p., illus., diagrs., figs. 3,000 fr.

Contents: Articles Biographiques. The ideas, work and writings of Dimitri Riabouchinsky, Basile Demtchenko. Liste chronologique des publications de Dimitri Riabouchinsky.

Mémoires. Conical, axially symmetric flows, G. Birkhoff and J. M. Walsh. Réflexions sur la mécanique classique, Georges Bouligand. Quelques résultats généraux concernant la détermination de solutions d'équations ellipitiques par les conditions aux frontières, P. Brousse et H. Pongin. Minimum virtual mass, A. Busemann. Entretien, par extension suivant son axe, d'une trombe rectiligne dans un fluide vixqueux, G. Darrieus. Effects of roughness and suction on transition from laminar to turbulent flow, H. L. Dryden. Sur l'intégration numérique des équations aux dérivées partielles, F. H. Van den Dungen. Influence de l'alimentation du sillage sur la trainée d'une plaque plane, L. Escande. Remark on the integration of the stress equations in plane plasticity, Hilda Geiringer. Le tir contre avions, Duc de Gramont. The range of application of the hydraulic analogy in transonic and supersonic aerodynamics, D. R. F. Harleman and A. T. Ippen. Weir wave suppressor, A. D. Hay. Überschallströmungen um langsam pendelnde Drehkörper, C. Heinz. L'influence des bord sur les couches limites, Einar Hogner. A note on friction resistance with special reference to ship forms, G. Hughes. Note on the estimation of aerodynamic forces on oscillating aerofoils in two dimensions, W. P. Jones. L'intégration de l'équation de la chaleur pour des données initiales

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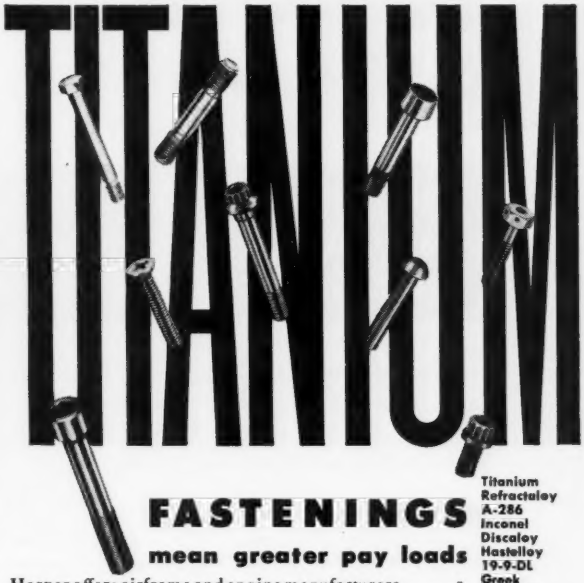

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Proceedings of the Third Midwestern Conference on Fluid Mechanics held at the University of Minnesota, Minneapolis, Minnesota on March 23, 24, and 25, 1953. Minnesota, University of Minnesota, June 1953. 783 p., illus, diagrs. figs. $6.00.

Contents: Part I, Symposium on Transport Phenomena: Survey of the equation of state and transport properties of gases and liquids, J. O. Hirschfelder. Review of transport processes in turbulent shear flows, A. M. Kuethe. Viscosity of suspensions—Review and application to two phase flow, Thomas Baron. A summary of sediment transportation mechanics—V., A. Vanoni. Some aspects of supersonic heat transfer, G. R. Eber. Passage of flow disturbances through a duct containing screens, shocks, or contractions, F. K. Moore.

Part II, Contributed Papers: Inviscid and Quasi-Inviscid Flow, A measure of unsteadiness of time dependent flows, V. G. Szebehely. Hydrodynamic earthquake forces on submerged structures, J. S. McNown. Determination of velocities on and near ducted bodies of revolution at 0° angle of attack in incompressible flow, B. A. Rabineau. Theory of the propeller in compressible flow, A. Busemann. The flow over a cone cylinder body at Mach number one, H. Yoshihara. Supersonic rotational flow over two-dimensional ogives, S. I. Pai. The linearized theory of supersonic flow about a thin wing, P. C. Rosenbloom. The decay of weak oblique shock waves in two-dimensional supersonic flow, R. Hermann. Strong shock wave decay and applications to aeronautical engineering problems, G. M. Arnold. Calculation of droplet trajectories using an electronic analogue computer, A. E. Abramson and W. L. Torgeson. The characteristics of sediment waves formed by flow in open channels, A. G. Anderson. Suppression of ship vibration by flow control, L. A. Baier and J. Ormondroyd.

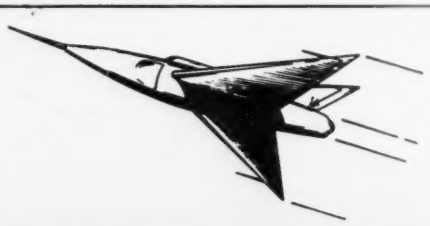
BALLISTICS

Uitwendige Ballistek (Exterior Ballistics). Dr. W. Bevelander. The Hague, Uitgeverij Excelsior, 1954. 165 pp., figs. (In Dutch)

The purpose of this monograph is to explain the theories which form the basis for the calculation of the data of trajectories for terrestrial and anti-aircraft guns under normal atmospheric conditions. The methods, which are discussed in detail—viz., the method of Siacci for terrestrial guns and the methods of Garnier, Haag, Marcus (1918) and Garnier, Haag, Marcus (1929) for antiaircraft guns—are now being used in Dutch centers for ballistics.

In the first chapter certain formulas for trajectories in vacuum are derived, together with the equation of the safety curve. Chapter 2 discusses the disturbances of the equilibrium of the atmosphere caused by a projectile flying at subsonic, sonic and supersonic velocities, respectively. All external influences on a projectile rotating in the atmosphere are analyzed in Chapter 3, together with the simplifications needed for the mathematical treatment of the problem. Chapter 4 is devoted to the theory of the air resistance and an explanation of various air-resistance laws.

The fifth Chapter describes the methods used to allow for the density of the air in ballistic problems. In Chapter 6 the differential equations of the trajectory are given assuming that the projectile may be regarded as a material point. Chapter 7 discusses some general properties of the trajectory in the atmosphere. In Chapter 8 the main problem of exterior ballistics and the five different ways in which this problem can be solved is explained. The approximate main ballistic equation is integrated in Chapter 9, with the use of the so-called primary functions. Didion's and Dicion-Bernoulli's methods and the first and the second method of Siacci are mentioned here. The formulas derived in Chapter 9 are used in Chapter 10 to derive the formulas used in Siacci's third method, introducing the so-called secondary functions. Fasella's tables which are needed for this method, are also discussed. Chapter 11



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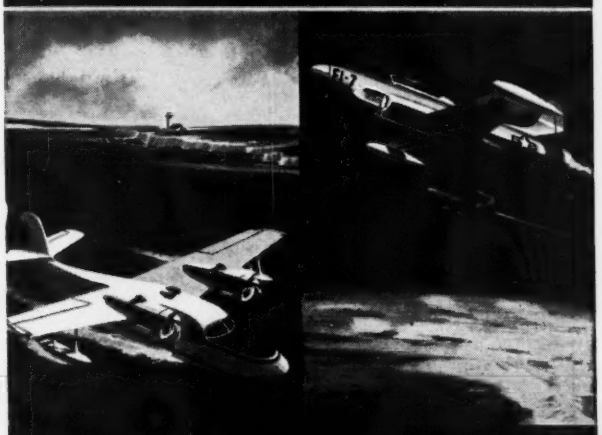

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discusses the solution of the main problem of exterior ballistics with the help of a series of the McLaurin. Piton-Bressant's and Duchêne's methods are also mentioned in this connection. Finally, Chapters 12 and 13 present a detailed derivation of the two methods of Garnier, Haag, Marcus used for the computation of antiaircraft trajectories. A complete derivation is given of the mathematical theory which forms the bases of these methods. Because more accurate values should be obtained for these antiaircraft trajectories, they are computed arc by arc. Moreover these methods have the advantage that the accuracy of the calculated values can be kept under control.

GRAPHICS

Graphics in Engineering and Science. A. S. Levens. New York, John Wiley & Sons, Inc., 1954. 696 pp., illus., diagrs., figs. $7.00.

This approach to graphics has two principal objectives: to help the reader gain a fuller appreciation of this mode of expression; and to enable him to use it in analyzing and solving problems in science and engineering. The book's explanations and examples show the most effective combination of the elements of graphics in design, research, and development, and provide material for the integration of graphics with other topics such as mathematics, mechanics, strength of materials, and design. The work is in three parts. The first of these provides a thorough grasp of the fundamentals of orthogonal projection, applying the basic concepts to a variety of problems with emphasis on the analysis necessary for their solution. Part Two deals with recognized standards of graphical representation, giving adequate attention to good technique and emphasizing the development of facility in freehand sketching and the simplification of drawings. Part Three is concerned with graphical solutions and computations. It shows the power of graphical methods, including graphical calculus in the solution of a wide variety of problems. Full material on matters such as lettering and geometrical construction will be found in the appendixes. Throughout the book, examples and problems are utilized to aid the reader's understanding. A selected bibliography has been included by the author who is Professor of Engineering Design, University of California.

HYDRAULIC EQUIPMENT

Hydraulic Systems and Equipment. R. Hadekel. New York, Cambridge University Press, 1954. 224 pp., illus., diagrs., figs. $3.75.

In a few pages of the introductory chapter the author outlines the necessary elements of fluid mechanics; he devotes the rest of his book to specific discussions of design problems, how they are solved, and the components of different hydraulic systems. Detailed information is given on those systems used to control airplanes, automatic machine tools, etc., and to transmit power in such machines as automobile brakes, fork trucks, and hydraulic presses. Of particular interest are the types of systems such as series sequence systems and variable area systems. Mr. Hadekel, who is a consulting engineer in London, writes for designers, shop foremen and maintenance engineers and all who use hydraulic machinery, and for students and teachers in technical colleges and engineering faculties. Much of the material of this book appeared first as a series of articles in *Machine Design* in 1953.

MATERIALS

Metallurgical Dictionary. J. G. Henderson and J. M. Bates. New York, Reinhold Publishing Corporation, 1953. 396 pp., illus., diagrs., figs. $8.50.

Arranged specifically for the needs of all metal industries, this reference book contains over 5,000 informative definitions and descriptions covering all the most essential terms in both production and physical metallurgy. Semiencyclopedic in nature, its sole purpose is to provide a comprehensive, easy-to-use, thoroughly up-to-date working

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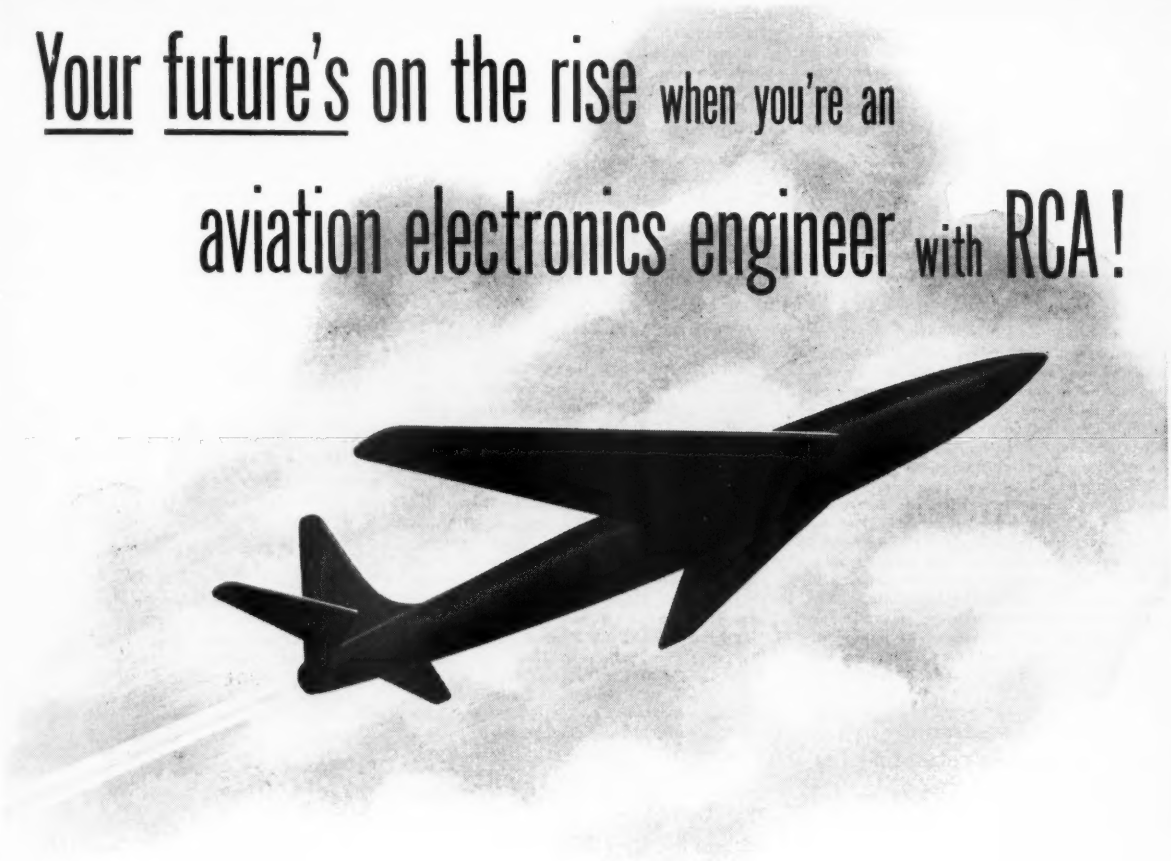

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tool for all those who manufacture or use metals and metal products. Original definitions are included of a sizable number of terms such as flame plating, shell molding, and others which have only very recently appeared in magazine literature. Particular care has been taken to cross reference entries of related terms. This has been done not only to facilitate reference to compound terms, but to direct the user from a synonym to a preferred term and to offer him a full coverage of available information.

Nonferrous Physical Metallurgy. Robert J. Raudebaugh. New York. Pitman Publishing Corporation, 1952. 345 pp., illus., diagrs., figs., $6.50.

It is the purpose of this book to discuss the more important nonferrous metals from the aspect of physical metallurgy. Particular emphasis is placed on recent developments in their processing, fabrication, and application. To cite a few instances: the melting and casting of reactive metals such as molybdenum; the direct casting of billets and slabs of aluminum, magnesium, and copper alloys; the fabrication of ductile titanium; and the application of powder metallurgy to the production of nonferrous parts are among the developments discussed and illustrated. Portions of tentative equilibrium diagrams are presented for a number of titanium and uranium alloy systems. Micrographs of commercial alloys and some of the newer materials (e.g., beryllium, both sintered and cast, and vacuum-cast molybdenum) have been included. An extensive up-to-date bibliography will be found for each chapter. The author is a professor at the Georgia Institute of Technology.

MATHEMATICS

Theory of Games and Statistical Decisions. David Blackwell and M. A. Girshick. New York, John Wiley & Sons, Inc., May, 1954. 355 pp., illus, diagrs., figs. $7.50.

Decision theory, believe the authors, applied to statistical problems the principle that a statistical procedure should be evaluated by its consequences in various circumstances. The mathematical model for decision theory is a special case of that for game theory, and in this book relevant parts of game theory—normal form, minimax theory, utility theory, etc.—are used as bases for a self-contained, rigorous exposition of statistical decision theory. In the formal development of the subject matter the authors have chosen to treat only discrete probability distributions, thereby avoiding all measure-theoretic difficulties. Continuous distributions, however, are used for illustrative purposes.

Theory of Functions of a Complex Variable. C. Carathéodory. New York, Chelsea Publishing Company, 1954. 301 pp., illus., diagrs., figs. $4.95.

This book is a translation of the last of the author's celebrated textbooks, which he completed shortly before his recent death.

PHOTOGRAPHY

High Speed Photography, Volume 4. New York, Society of Motion Picture and Television Engineers, 1952. 170 pp., illus., diagrs., figs., $2.50.

Foreword. Progress in Photographic Instrumentation in 1950, by K. Shaftan. Three-Dimensional Motion Picture Applications, by R. V. Bernier. A High-Speed Stereoscopic Schlieren System, by John H. Hett. High-Speed Motion Picture Cameras From France, by P. M. Gunzbourg. Letters to the Editor, by J. C. Kudar and J. H. Waddell. Optical Problems in High-Speed Camera Design, by J. C. Kudar. A Rapid-Action Shutter With No Moving Parts, by Harold E. Edgerton and C. W. Wyckoff. Use of Image Phototube as a High-Speed Camera Shutter, by A. W. Hogan. High-Constant-Speed Rotating Mirror, by J. W. Beams, E. C. Smith and J. M. Watkins. Light Source for Small-Area High-Speed Motion Picture Photography, by R. I. Derby and A. B. Neeb. Cine-Interval Recording Camera (Automax), by A. P. Neyhart. Simultaneous High-Speed Arc Photography and Data Recording with a 16-Mm Fastax Camera, by E. L. Perrine and N. W. Rodelius. Slide Rule for Analyzing High-Speed Motion Picture Data, by K. W. Maier. Film Reader for Data Analysis, by W. M. Clard and L. R. Richardson. A Time-Motion Study by Methods of High-Speed Cinematography, by H. W. Baer, B. F. Cohlan and A. R. Gold. Practical Application of High-Speed Photography in Business Machines, by W. L. Hicks and R. L. Wright. Continuous Processing Machine for Wide Film, by H. E. Hewston and Carlos H. Elmer. Cumulative Index to Volumes 1–4.

POWER PLANTS

Bibliography of Books and Published Reports on Gas Turbines, Jet Propulsion and Rocket Power Plants—January 1950 through December 1953. Ernest F. Fiock and Carl Halpern. (Supplement to National Bureau of Standards Circular 509.) Washington, D.C., National Bureau of Standards, July, 1954. 110 pp., illus., diagrs., figs. $0.50.

This Supplement to Circular 509 extends the period covered by the latter through December 1953, with an overlap of one year. Approximately 5,000 references to sources of information on gas turbines and jet propulsion that have been published in the last four years are included, as are some earlier reports that were originally classified for reasons of military security. To facilitate use of the bibliography, the references have been arranged according to their content.

Most of this literature survey has been made in the course of a broad program of combustion chamber research sponsored by the Bureau of Aeronautics, Department of the Navy.

SPRAYS

Bibliography on Sprays. Compiled by the Staff of the Department of Engineering Research, The Pennsylvania State University. 2d Ed. New York, The Texas Company, Refining Department, Technical and Research Division, December, 1953. 210 pp.

This bibliography came into being and grew in connection with research in the field of sprays carried on since 1927 at what was then called the Engineering Experiment Station of the Pennsylvania State College. The first edition, compiled by Dr. K. J. DeJuhasz and published in 1948, contained about 400 titles, with abstracts and subject index, covering mainly sprays, and to a lesser extent duct and other comminuted materials, also flow of fluids, applications, and experimental procedures. This second edition contains all listings appearing in the first edition with the addition of about 300 new titles. The subject index has been expanded so that now every title is listed under all applicable subject headings rather than under one heading only.

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Project Engineer—Project engineering position exists in a small research and development organization for a man qualified in stress analysis and design of aircraft and missile structures. Minimum of B. S. degree and 3 years' experience required. Submit résumé to Director of Research and Development, Narmco, Inc., 1882 Moore St., San Diego, Calif.

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Research Engineers—Aeroelastic and Structures Research Laboratory, M.I.T., offers staff positions to Research Engineers in the fields of aeroelasticity, structures, aerodynamics, plasticity, and thermoelasticity. Graduate study and research can be combined at salaries commensurate with experience. Graduate study is contingent upon admission to graduate school. Send particulars to: Aeroelastic and Structures Research Laboratory, Massachusetts Institute of Technology, Cambridge 39, Mass.

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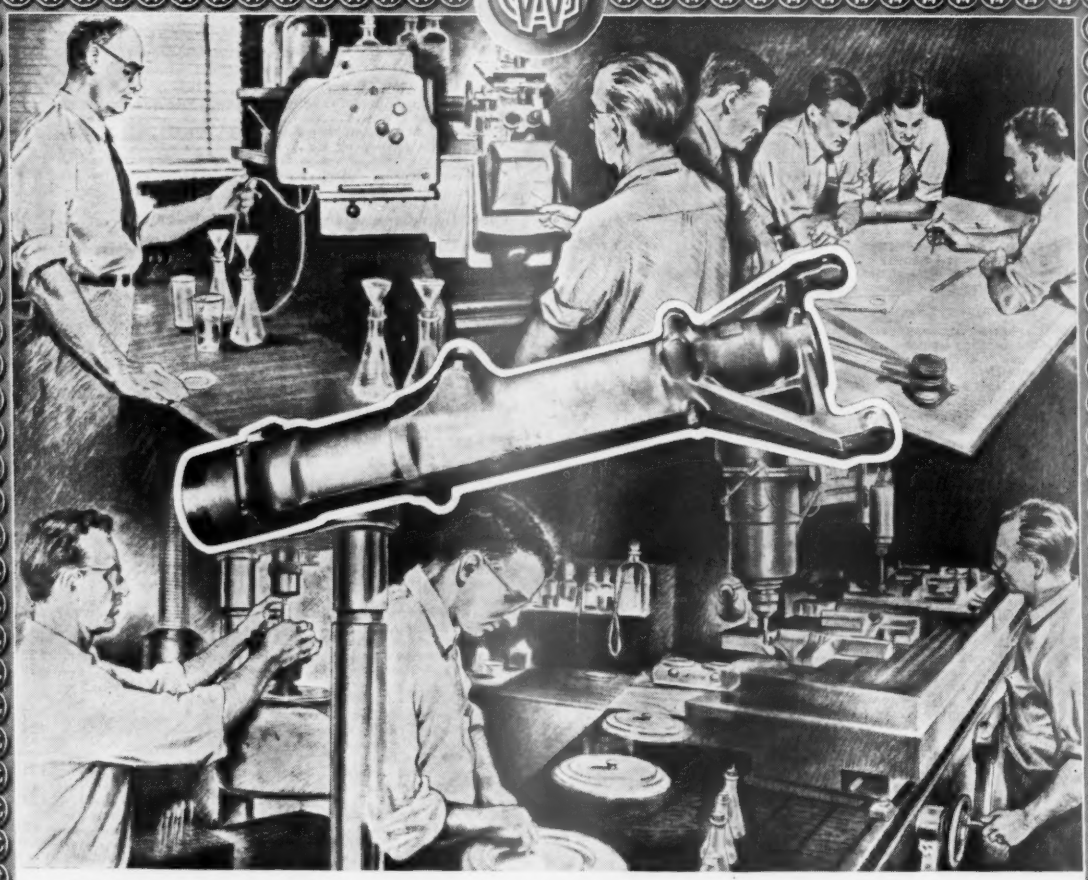

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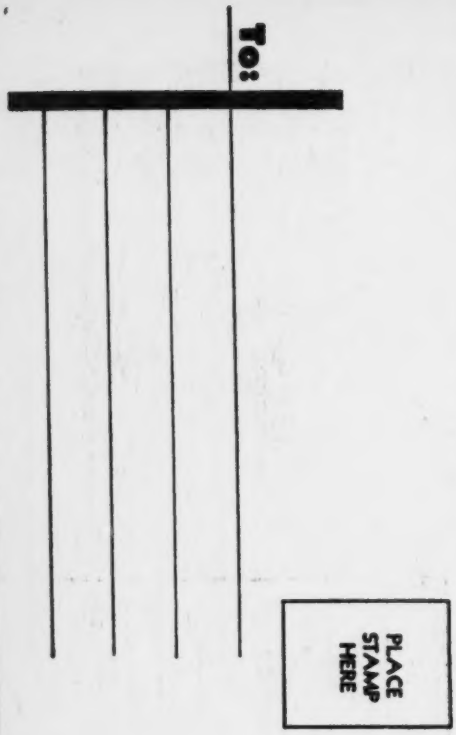

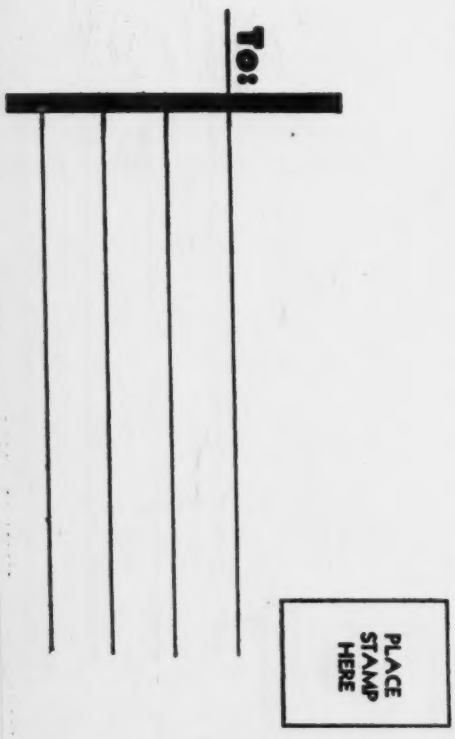

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X-Y Plotter & Recorder. Catalog. **Librascope, Inc., 1607 Flower St., Glendale, Calif.** *See page 134*

"Geneva-Loc" Electric Actuator. Catalog 114. **Pacific Div., Bendix Aviation Corp., 11600 Sherman Way, North Hollywood, Calif.** *See page 98*

Cable Tension Regulators. Publication *Aero News*. **Pacific Scientific Co., 1430 Grande Vista Ave., Los Angeles, Calif.** *See page 8*

Absolute Pressure Gage. Publication No. TP-28-A. **Wallace & Tiernan Inc., 25 Main St., Belleville 9, N.J.** *See page 141*

"Stratopower" Electric Motor Driven Hydraulic Pumps. **Watertown Div., New York Air Brake Co., 760 Starbuck Ave., Watertown, N.Y.** *See page 95*

Sensitrol Relays. Bulletin. **Weston Electrical Instrument Corp., 614 Frelinghuysen Ave., Newark 5, N.J.** *See page 6*